

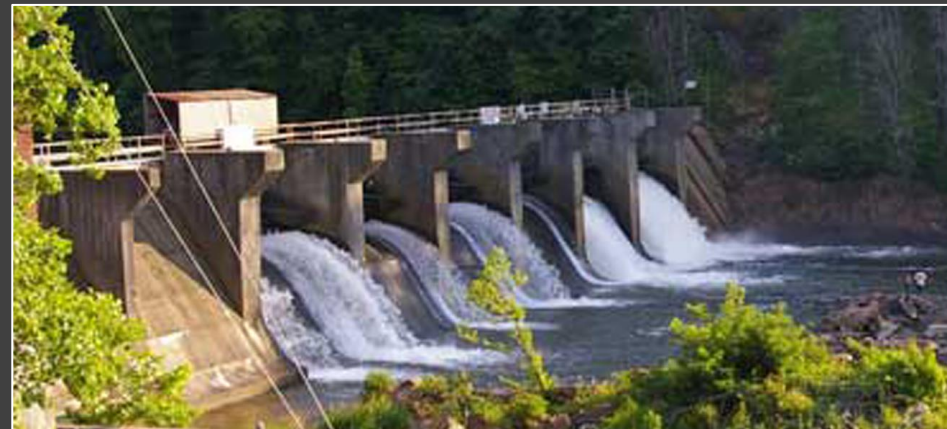
# **Streams in a Changing Landscape: Identifying Candidate Reference Reaches to Assess the Physical and Biotic Integrity of Missouri's Wadeable Streams**



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# Flowing Waters: Diversity and Status

- **Multitude of “services”**
  - Food and drinking water supply
  - Crop irrigation
  - Hydroelectricity
  - Freight transport
  - Waste removal
  - Recreational opportunities





# Flowing Waters: Diversity and Status

- Freshwater systems approximate ~ 0.01% Earth's total water
- ~ 1/3 of all vertebrate species, including over 40% of described fish species reside in lakes and rivers
- United States is a “hotbed of temperate freshwater diversity”
  - >10% of all freshwater fish species
  - ~30% of mussel species
  - >60% of freshwater crayfish species
- Missouri – over 210 species of fish and ~70 mussel species



# Flowing Waters: Diversity and Status

- Owed largely to dynamic, spatially complex processes occurring in stream channels, riparian zones, and floodplains
- Highly interconnected with their landscapes
  - “The valley rules the stream” (Hynes 1975)
- “Riverine landscapes”
  - Shifting mosaic of successional habitat
  - Highly heterogeneous



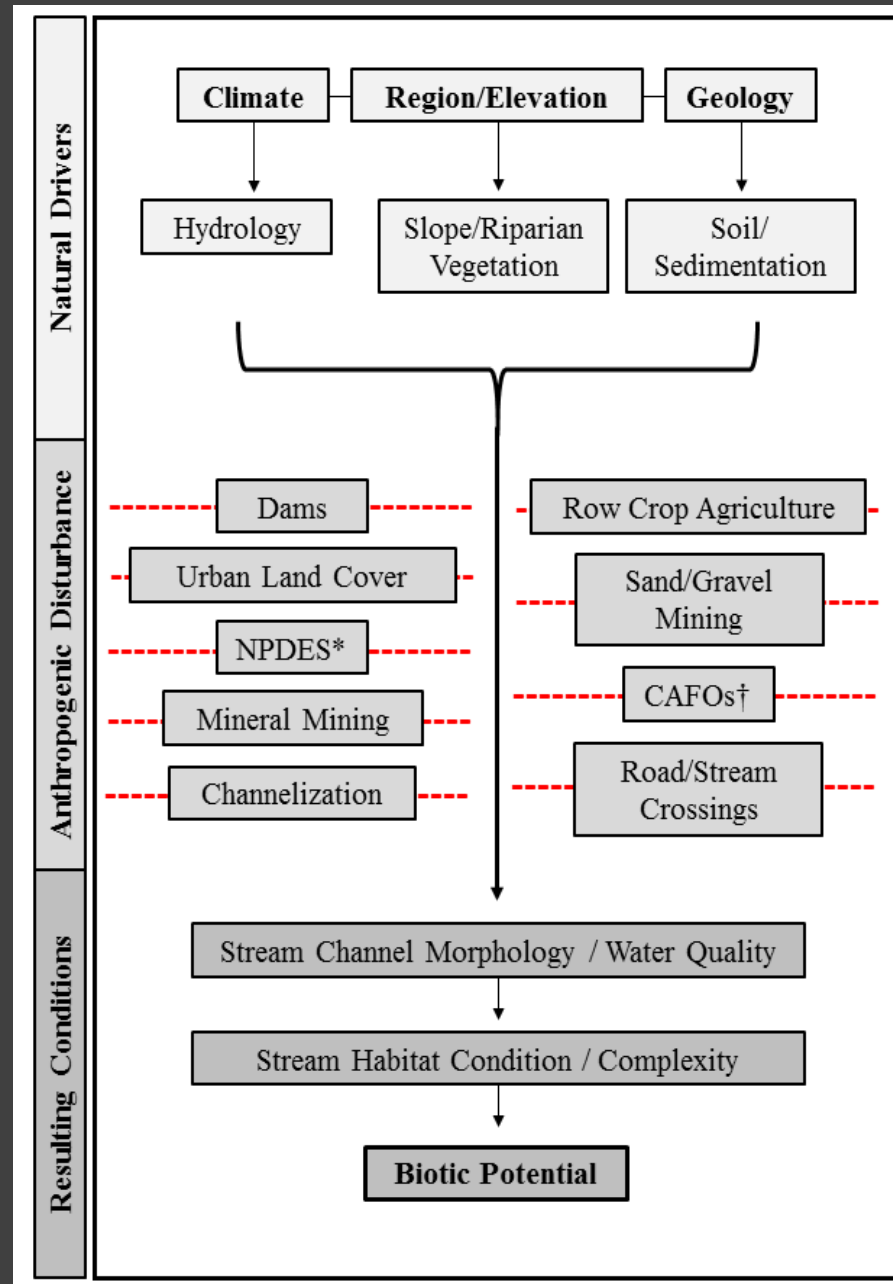


# Flowing Waters: Diversity and Status

- **“Freshwater biodiversity crisis”**
  - >120 North American freshwater species extinct since 1900 (Ricciardi and Rasmussen 1999)
- **Over 700 North American fish species listed as endangered, threatened, or vulnerable**
  - 92% increase since 1989 (Jelks et al. 2008)
- **Nearly 1/3 of Missouri fish species and over half of mussel species listed as imperiled or of conservation concern**
  - (Missouri Natural Heritage Program 2013)



# A Changing Landscape





# A Changing Landscape

- **Altered stream flow regimes**

- Reduced magnitude and frequency of high flow events facilitate non-native invasions
- Increased flow stability and water velocity disrupts species' life cycles and habitat use
- Altered discharge timing disrupts spawning and migration cues
- Fragmented habitat



# A Changing Landscape

- **Altered channel characteristics stemming from anthropogenic disturbance**
  - Increased sedimentation
  - Reduced woody debris availability
  - Unstable stream banks and incised channels





# A Changing Landscape

- **Water quality impairment (excess nutrients, ions, heavy metals, and pesticides)**
  - Urban and agricultural runoff
  - Mine waste
  - Wastewater treatment discharge
- **Species and/or ecosystem function loss**



# Purpose and Objectives

- Missouri has experienced tremendous habitat loss and degradation
- Need exists for stream assessment tools to characterize stream impairment and identify areas of high restoration need and conservation value
  - How have landuse practices altered stream habitat and biotic composition?
  - What are the physical and biotic characteristics of remaining high-quality or least-disturbed streams?





# Purposed and Objectives

- **Clean Water Act 1972**
  - Shifted the focus of stream conservation and restoration to a biological endpoint rather than human health and recreational needs.
- **Stated goal of assessing and restoring “biological integrity”**
  - “The capability of supporting or maintaining a balanced, integrated, adaptive community of organisms having species composition, diversity, and functional organization comparable to that of natural habitat of the region” – Karr and Dudley 1981
- **Has lead to the advent of multi-metric biotic indices using fish and invertebrate community characteristics to assess biological integrity and designate biological criteria**



# Purpose and Objectives

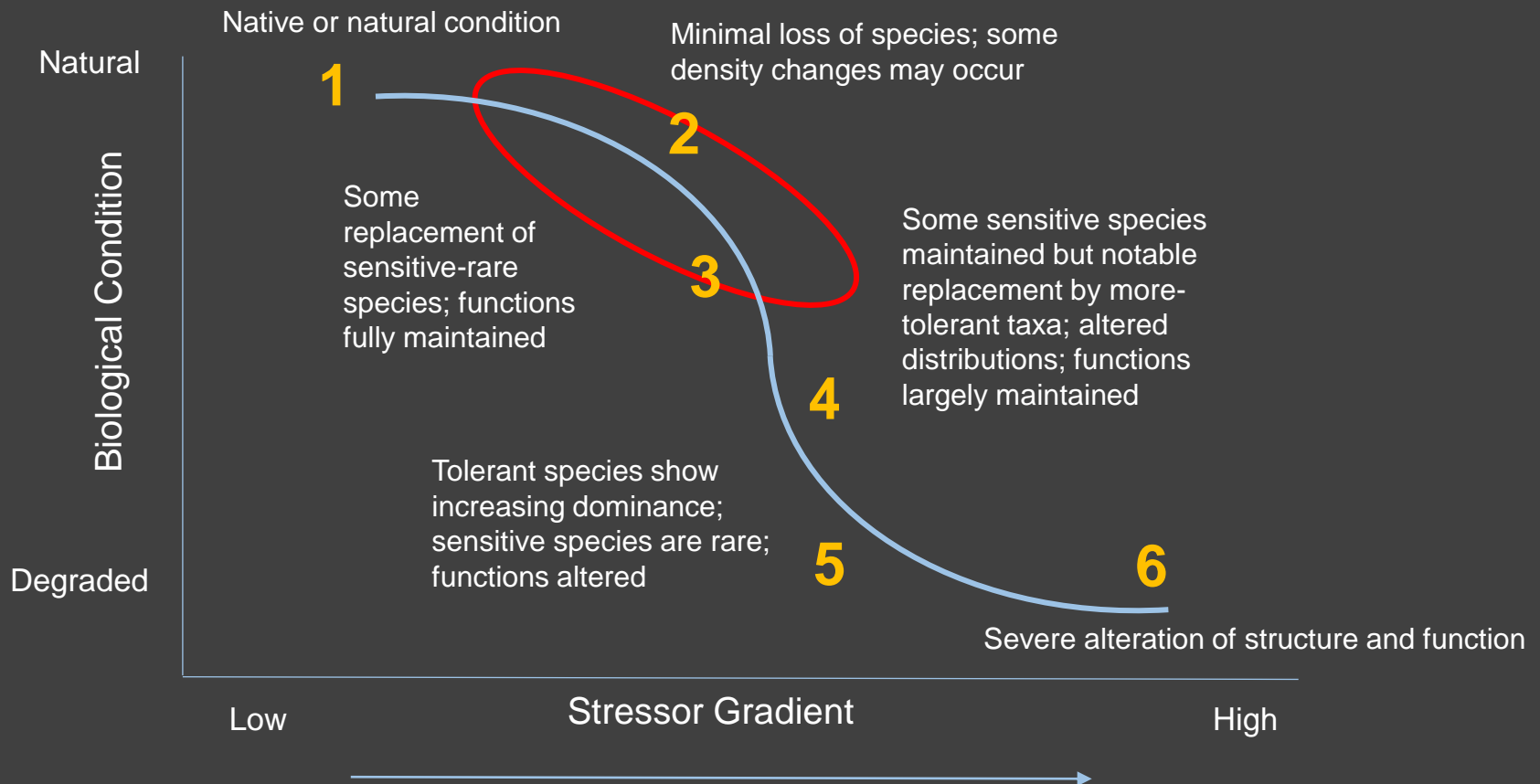
- **The reference reach concept**
  - Streams reflecting habitat and biotic characteristics thought to occur naturally within a particular ecoregion
  - “Historic”, “least-disturbed”, “best attainable”



# Purpose and Objectives

- **The biological condition gradient**

- Davies and Jackson 2006





# Purpose and Objectives

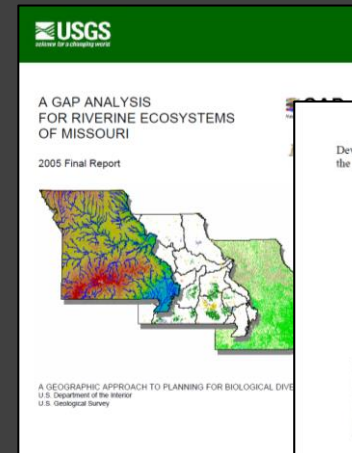
- **Hughes et al. (1986) criteria**
  - Identify relatively homogenous stream regions
  - Evaluate regional disturbance types and intensities
  - Select regional candidate sites exhibiting the least amount of disturbance
- **Efforts to quantify reference conditions are complicated by:**
  - Covariance of natural and anthropogenic disturbance gradients
  - Potential legacy effects of previous landscape alterations
  - Uncertainties concerning the relative impact of multiple stressors and possible threshold effects
  - Delineating ecologically significant, yet manageable ecoregion classifications



# Purpose and Objectives

Best professional judgment  
following Hughes and Omernik  
Criteria

Data-based “top down”  
characterization of stream  
health



# Purpose and Objectives

- **Threat indices often lack in-stream biological data to train and test their models, and have limited ability to answer specific questions such as:**
  - What is the impact of a given threat upstream?
  - Of the many threats upstream, which is worse?
  - How exactly do these threats alter the physical, chemical, and biological character of the stream?
- **Replacing subjective methodology with a more defensible, data-based approach**
- **Linking watershed characteristics to local environmental and biotic conditions necessary for a mechanistic understanding of impairment and better diagnoses and restoration actions**



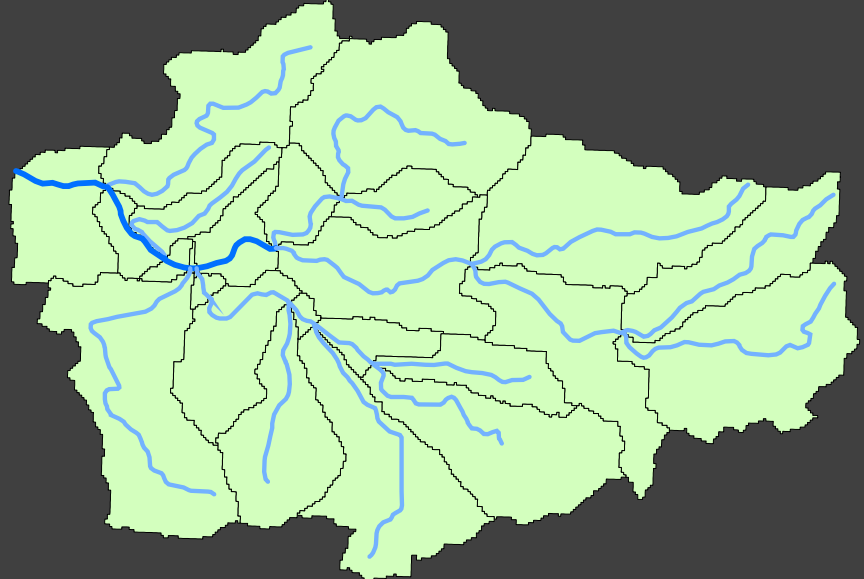
# Purpose and Objectives

- **Our specific objectives were:**
  - To assess the influence and relative importance of reach and watershed-level environmental variables on stream fish and macroinvertebrate community characteristics
  - To determine the relationship between reach-level habitat and water quality and watershed-level environmental characteristics
  - To predict statewide stream biotic conditions and develop a quantitative method for identifying candidate regional stream reference sites.
  - To develop a provisional headwater threat index

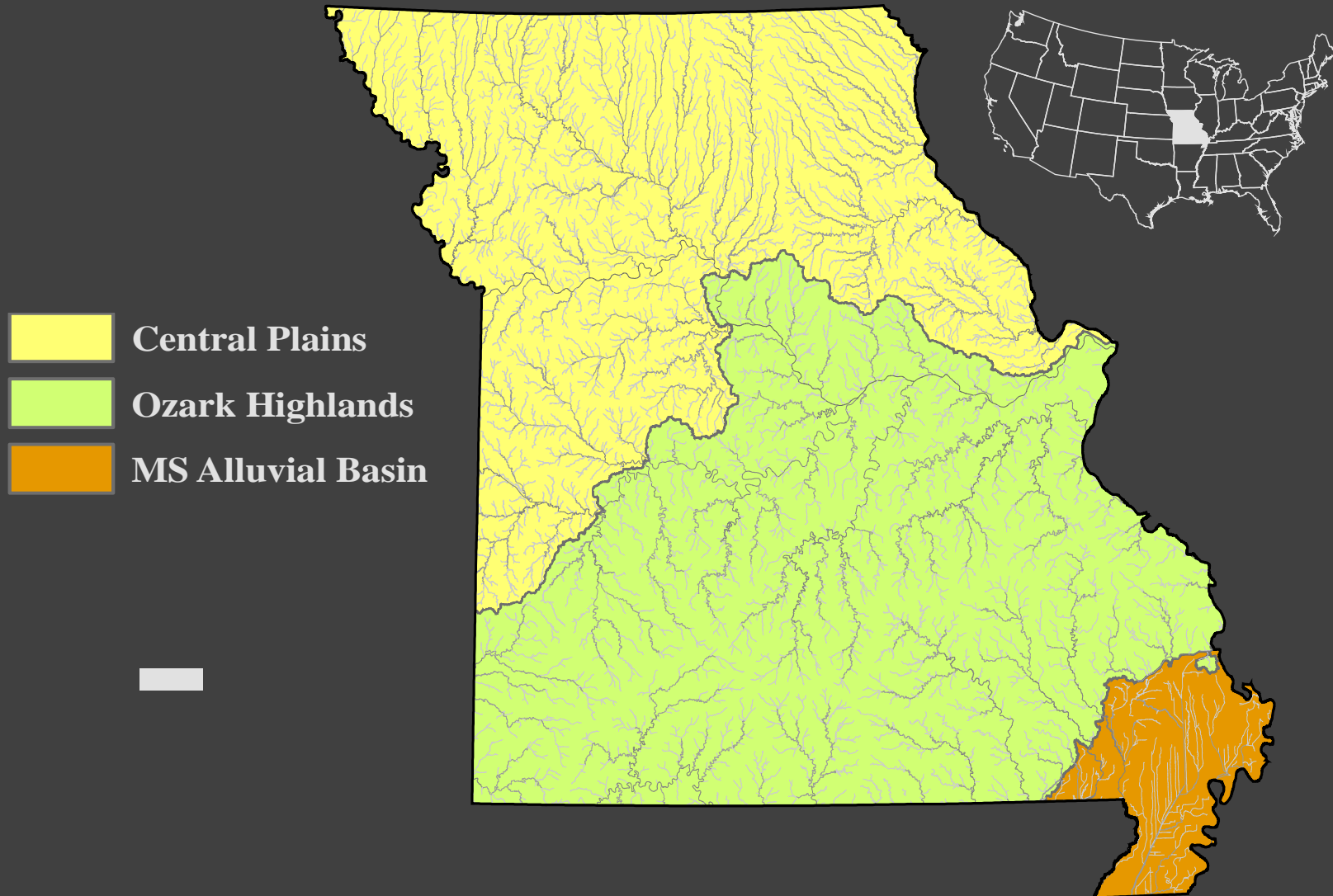


# Study Regions and Spatial Framework

- **Study focused on “creeks” and “small rivers” of Missouri**
  - Delineated using shreve-link magnitude ranges, with mean watershed areas of  $\sim 60 \text{ km}^2$  and  $480 \text{ km}^2$ , respectively
- **Spatially referenced habitat and biotic data to modified version of 1:100,000 National Hydrography Dataset**
  - ArcGIS 10.2
  - RivEX



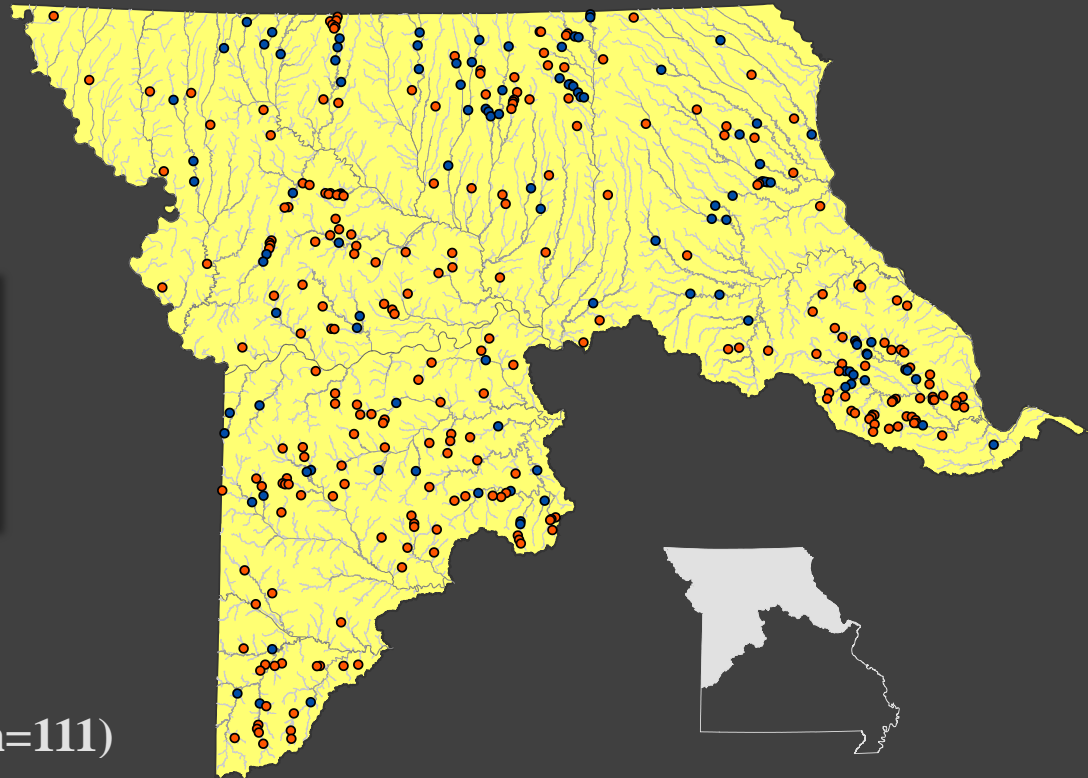
# Study Regions and Spatial Framework





# Study Regions and Spatial Framework

- **Dissected Till Plains (Central Plains)**
  - Low, rolling hills, broad river valleys
  - Low gradient streams with silty or fine gravel substrates
  - Fish community generally consists of widespread, tolerant taxa

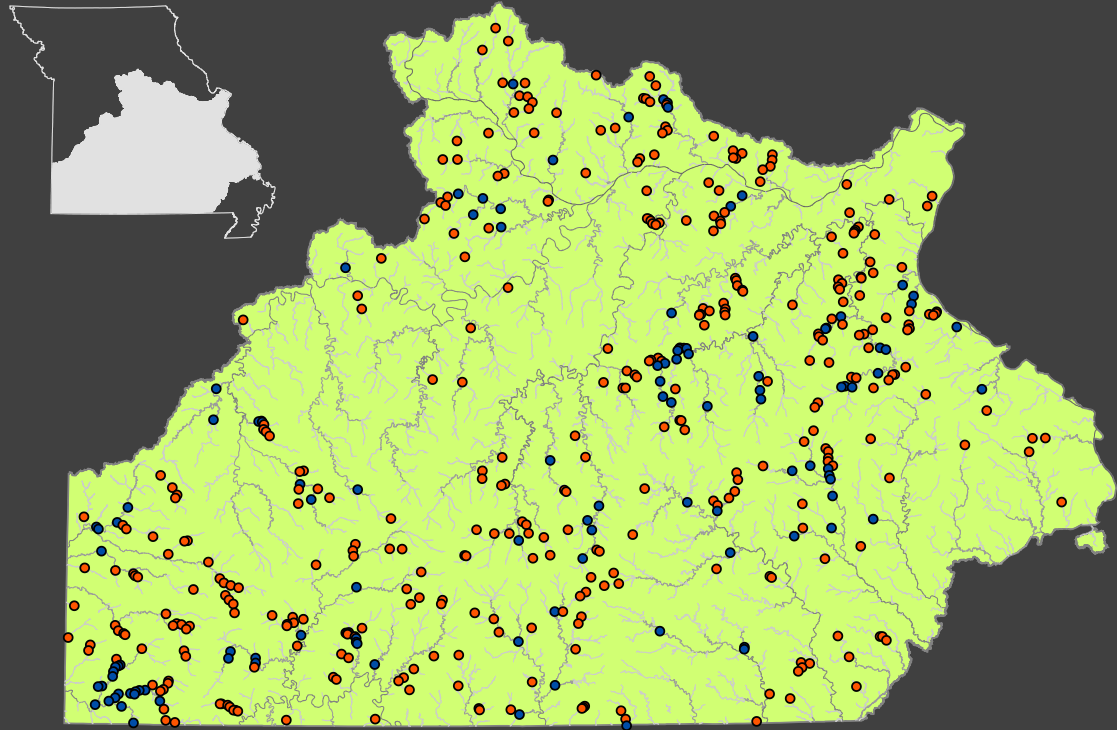


- Creeks (n=278)
- Small Rivers (n=111)

# Study Regions and Spatial Framework

- **Ozark Highlands**

- Highly dissected plateau, deep and narrow river valleys, high local relief
- Higher stream gradients, considerable groundwater input, high dissolved oxygen and coarse gravel substrate
- As a whole, supports a large number of endemic and sensitive aquatic fauna

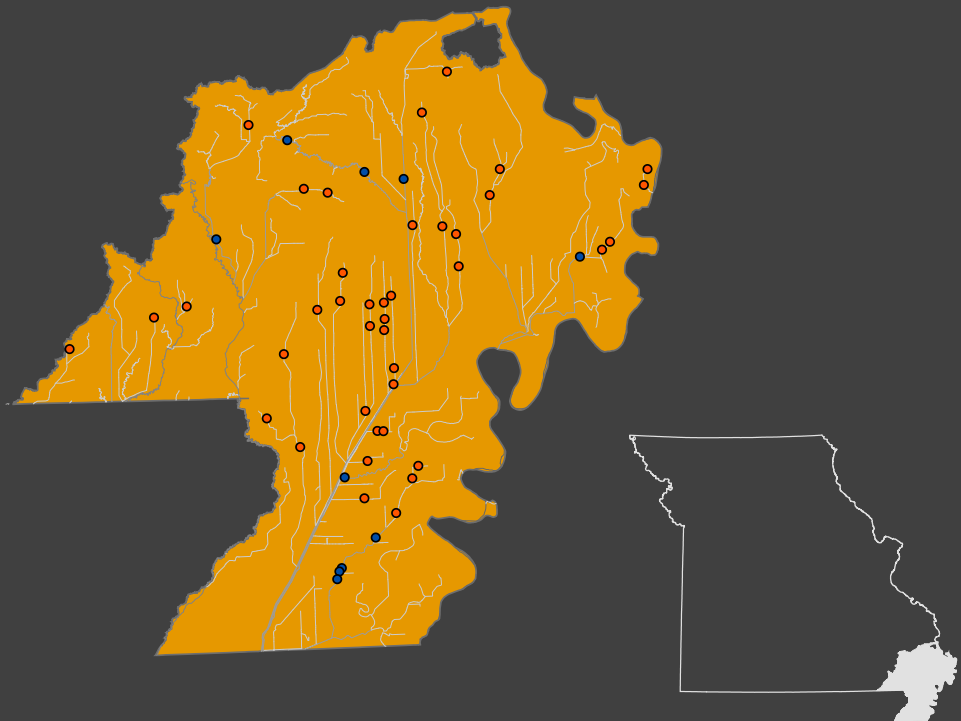


- Creeks (383)
- Small Rivers (n=121)

# Study Regions and Spatial Framework

- **Mississippi Alluvial Basin**

- Broad, flat alluvial plain
- Highly vegetated streams with low dissolved oxygen and silty and fine gravel substrate
- Fish fauna remains distinctive and more varied than that of the Plains



- **Creeks (41)**
- **Small Rivers (n=10)**



# Biological Data

- **Fish collection**

- MDC's Resource Assessment and Monitoring Program
- Random samples from late May – early October (2000-2014)
- Single pass electrofishing and seining of a block-netted reach

- **Macroinvertebrate collection**

- MoDNR's Semi-Quantitative Macroinvertebrate Bioassessment Protocol
- Return visits to fish sampling sites (September and October)
- Six kick net samples from each of three primary habitat types (flowing-water coarse substrate, non-flowing water depositional substrate, and root mat substrate)
- Specimens returned to laboratory for identification to genus level, and species when possible



# Biological Data

- Community-level analysis
- We summarized fish and macroinvertebrate data to reflect various aspects of stream community structure and function
  - Richness and diversity
  - Habitat preference
  - Trophic ecology
  - Reproductive ecology
  - Sensitivity to disturbance



# Biological Data

- **Richness and Diversity**

- Number of native fish species – decrease
- Shannon Diversity Index (Invertebrate) – decrease



- **Habitat Preference**

- Number of native benthic species – decrease

- **Trophic Ecology**

- Proportion of native insectivorous cyprinid individuals – decrease
- Proportion of native omnivorous/herbivorous individuals – increase



- **Reproductive Ecology**

- Number of native lithophilic species – decrease

- **Sensitivity to Disturbance**

- Proportion of native tolerant individuals – increase
- Proportion of non-native individuals – increase
- Ephemeroptera, Plecoptera, Trichoptera Richness (Invertebrate) – decrease
- Hilsenhoff Biotic Index (Invertebrate) – increase





# Reach-level Environmental Data

- **MDC's Resource Assessment and Monitoring Program**
  - EPA's EMAP Protocol
  - Water quality data collected using handheld meters
  - Habitat data collected at 11 cross-channel transects dividing the reach into tenths
- **Channel Morphology**
  - Sinuosity, width/depth ratio, channel incision height, etc.
- **Substrate**
  - Size and variability, embeddedness, etc.
- **Cover and Shading**
  - Large woody debris, undercut banks, canopy density, etc.
- **Water Quality**
  - Dissolved oxygen, conductivity, turbidity, etc.



# Watershed-level Environmental Data

- Calculated existing land-use/land-cover data for local and network catchments, and local and network riparian zones
  - 19,736 creek segments, 8,937 small river segments
- 2011 National Land Use/Land Cover dataset
- Point-stressors compiled for Missouri's Human Threat Index



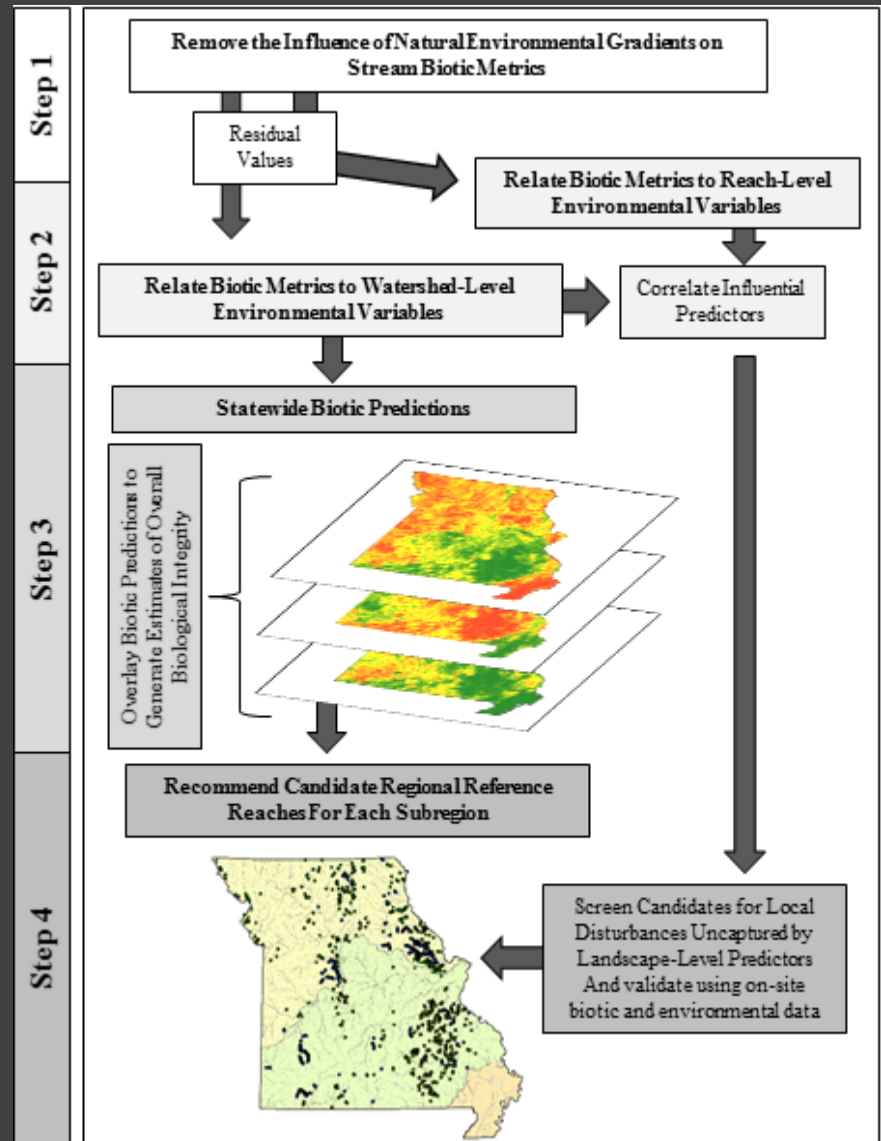
# Watershed-level Environmental Data

- **Fragmentation / Flow Modification**
  - Dams, headwater impoundments, road crossings, wells
- **Urbanization**
  - Developed (open and low intensity), developed (medium intensity), developed (high intensity), total imperviousness, 2010 population density, 2000-2010 population change
- **Agriculture**
  - Row-crop agriculture, pasture land
- **Point Source Pollution**
  - Coal mines, lead mines, confined animal feeding operations, national pollution discharge elimination systems, landfills, hazardous waste sites, superfund sites
- **Natural Landcover**
  - Forest, grassland, wetland



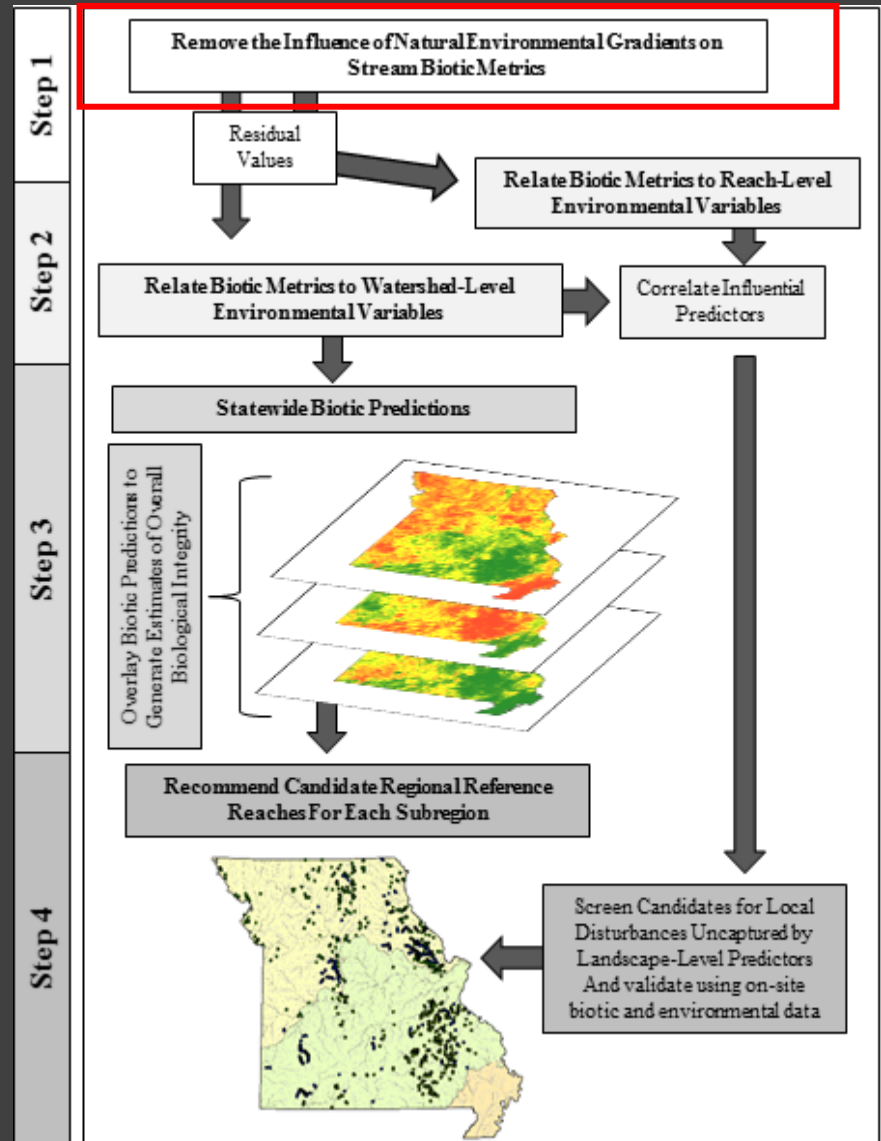
# Determining the influence of human alterations and identifying least-disturbed stream reaches

- **Step 1)**
  - Account for natural sources of biological variation
- **Step 2)**
  - Relate biotic metrics to
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  - Link reach and watershed-level environmental characteristics
- **Step 3)**
  - Predict biotic metrics for each stream reach statewide using watershed-level data
- **Step 4)**
  - Select streams scoring at top of biological integrity gradient as candidate reference reaches for each size class and aquatic subregion

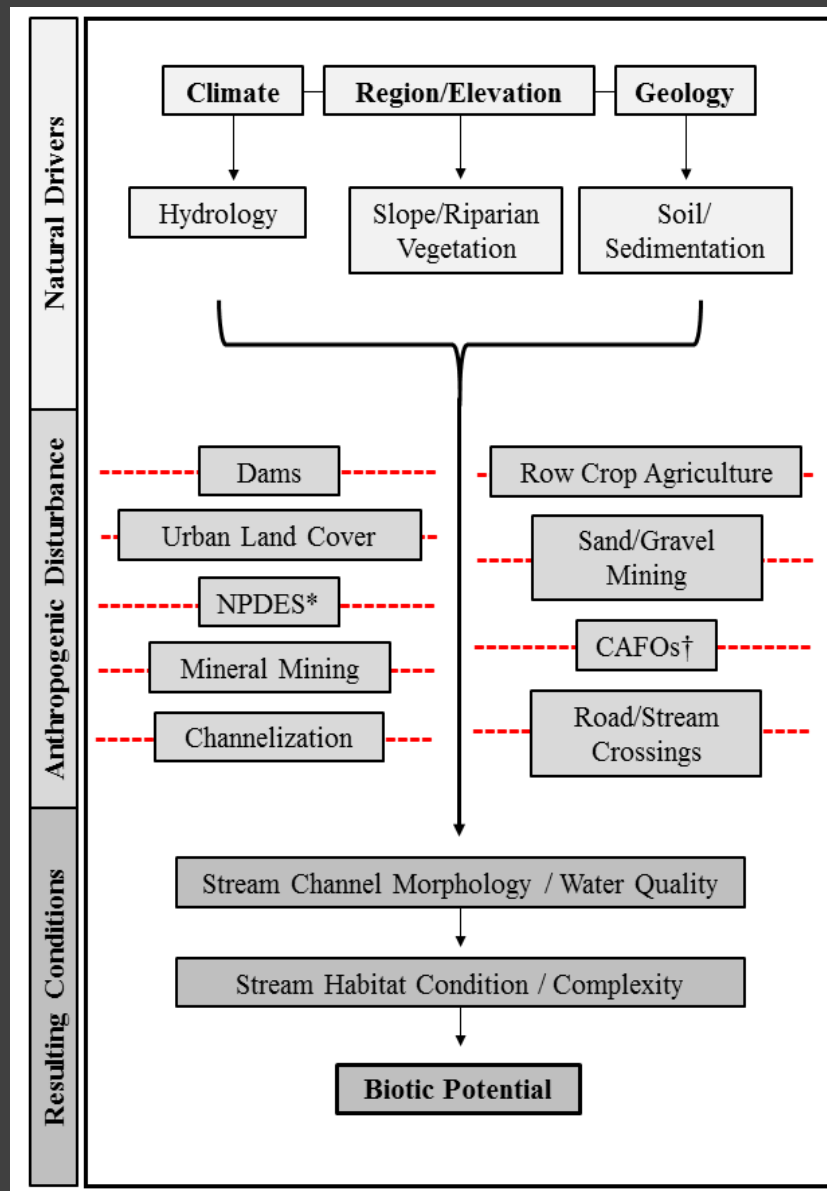


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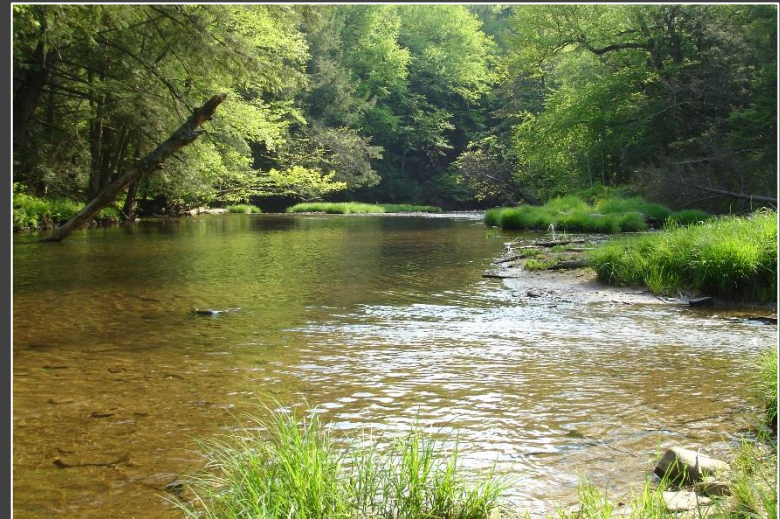


# Accounting for Natural Sources of Biological Variation



# Accounting for Natural Sources of Biological Variation

- Accounting for natural sources of variation in stream habitat and biotic composition is critical for accurately assessing stream health
- Even within stream size class and aquatic subregion, major differences can occur
  - Stream size, gradient, network positioning, sampling month, etc.



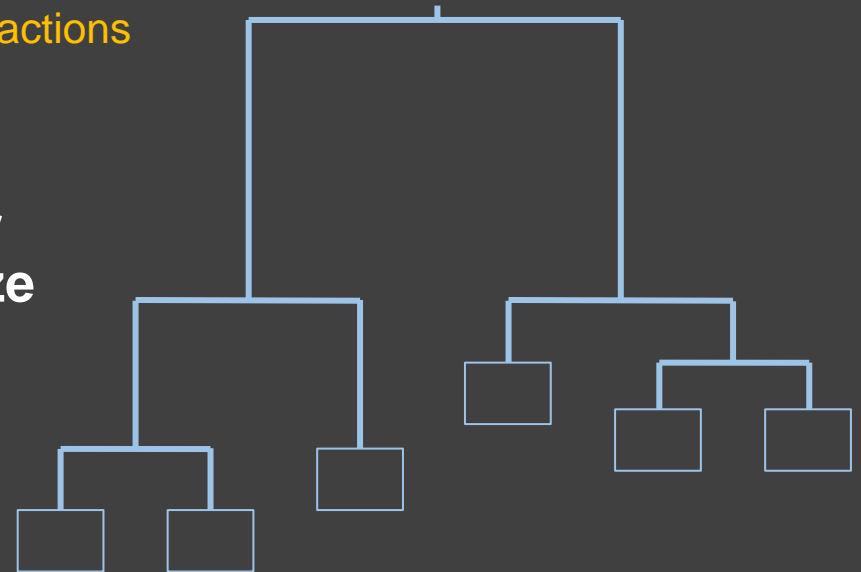


# Accounting for Natural Sources of Biological Variation

- **Boosted Regression Tree Models**

- Non-parametric, machine-learning method
- Uses a boosting algorithm to combine many simple regression trees to enhance predictive performance
- Fit nonlinear responses
- Incorporate higher-order predictor interactions
- Can handle missing data
- Uninfluenced by outliers

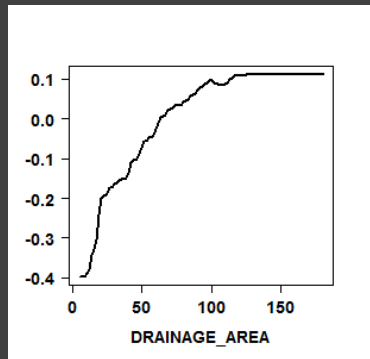
- **Constructed separate models for each response metric, stream size class, and aquatic subregion**



# Accounting for Natural Sources of Biological Variation

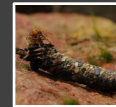
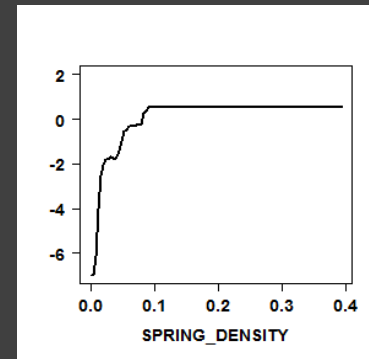
Number of Native Fish Species –  
Plains Creeks

numnatp



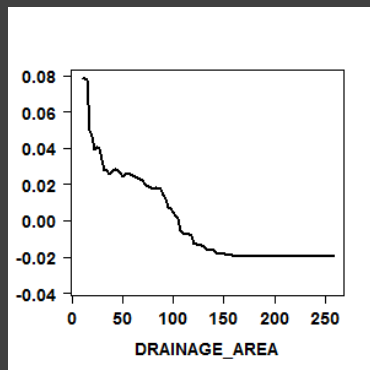
EPT Richness – Ozark Small  
Rivers

EPT



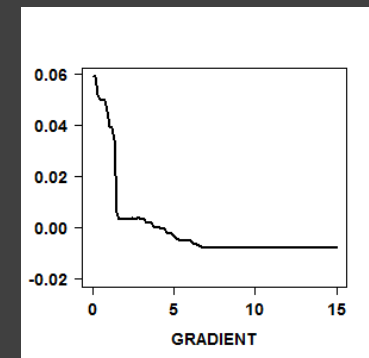
Proportion of Native  
Omnivorous/Herbivorous  
Individual – Ozark Creeks

pnomb



Proportion of Native Tolerant  
Individual – Plains Creeks

pnptole

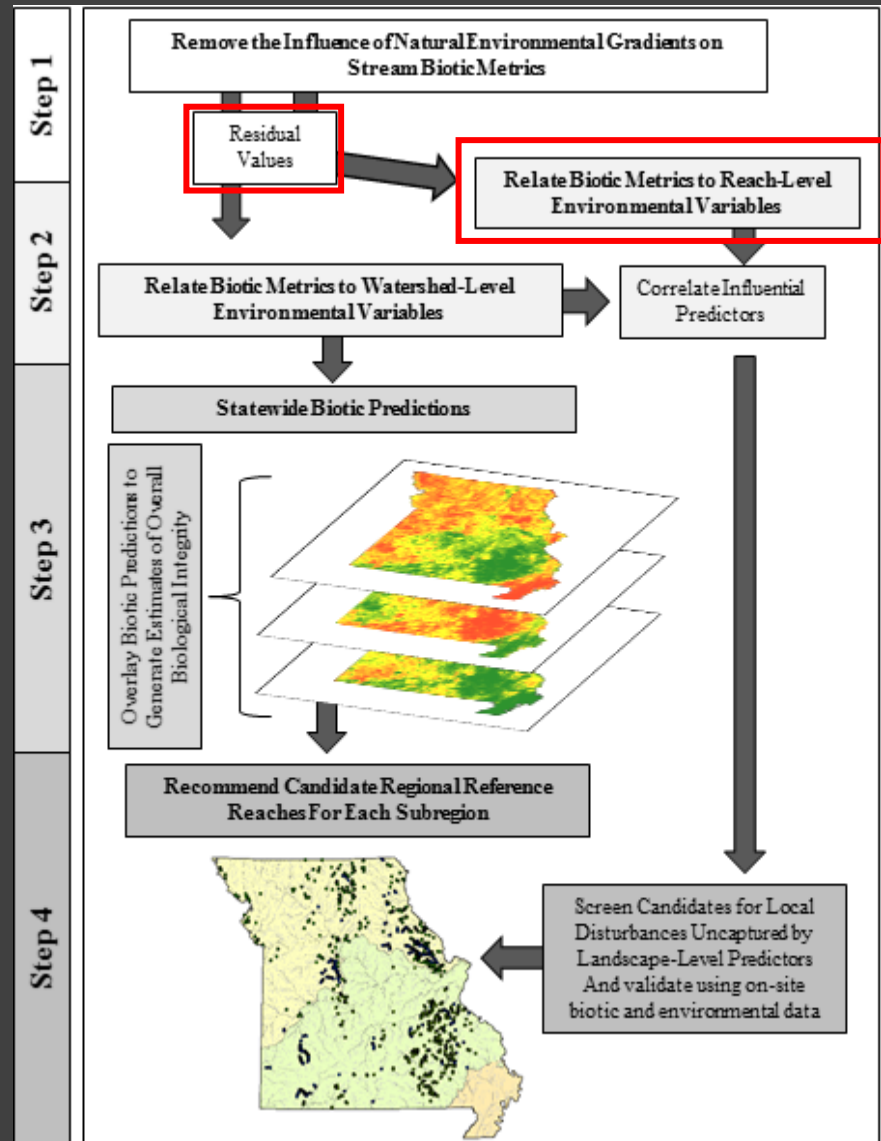


# Accounting for Natural Sources of Biological Variation

- **Models overall accounted for ~15% variation in biotic response metrics, and as much as 39% of variation (nsnbenth Plains small rivers)**
- **Drainage area and fine surficial geology consistently among top predictors for fish richness measures**
  - >50% explained variation in numnatasp, nsnbenth, nsnlith
- **Spring density influential for invertebrates and proportional fish metrics**
  - 35% - 45% explained variation in EPT, HBI, pnincyp, pnomhb, pntole
- **Species richness decreases as distance to mainstem river increases**
- **Sampling month relatively uninfluential**

# Determining the influence of human alterations and identifying least-disturbed stream reaches

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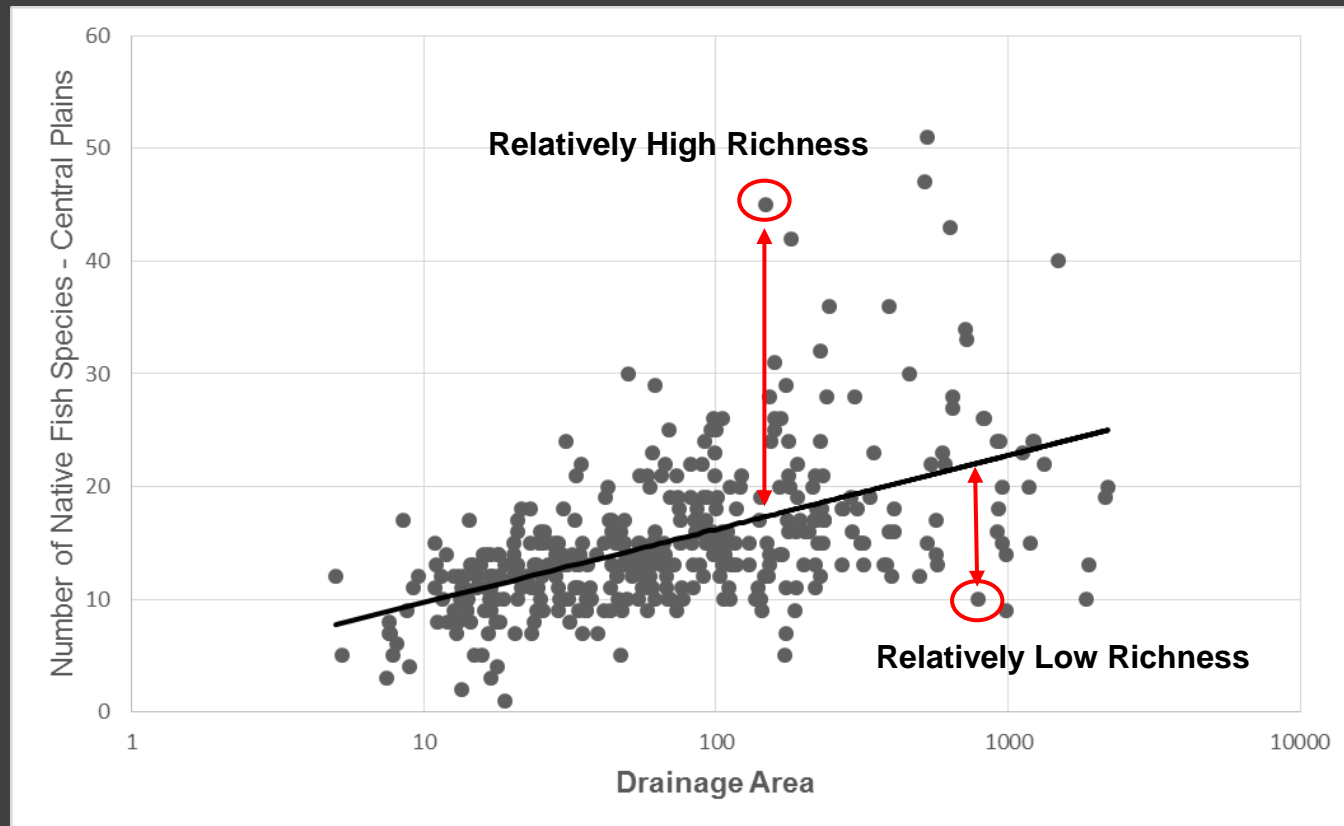




# Determining the Influence of Reach-level Environmental Variables

- **Residual Analysis**

- Biotic metric values in relation to other streams with similar natural environmental characteristics (i.e. drainage area, reach gradient, spring density, etc.)



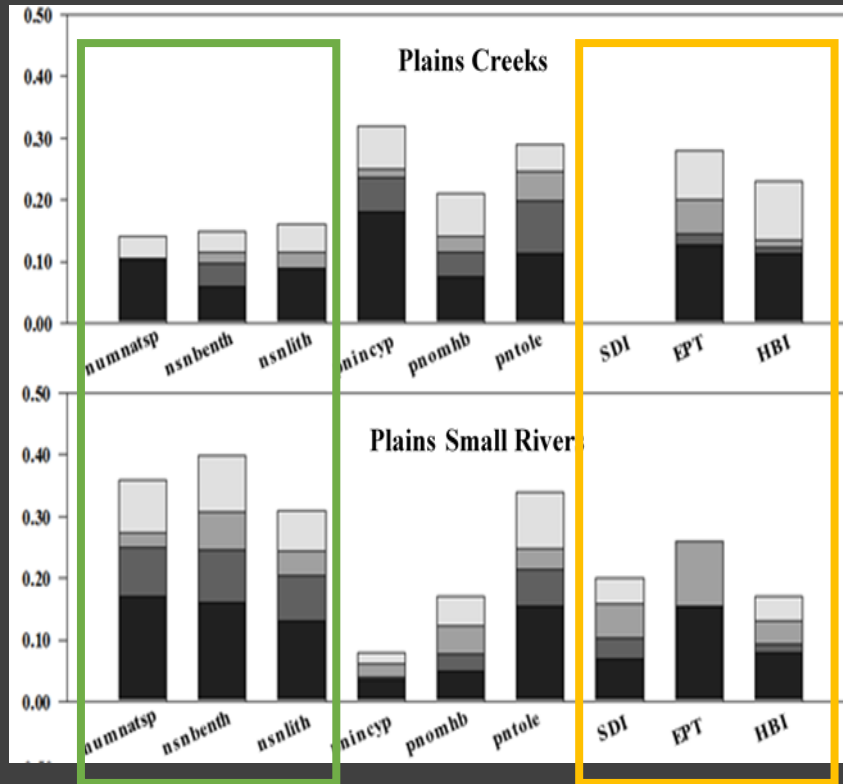
# Determining the Influence of Reach-level Environmental Variables

- 30 predictors evaluated after removing 9 highly correlated variables of the initial 39 (Pearson  $r = |0.70|$ )
- Successfully constructed boosted regression tree models for nine of ten biotic metrics for at least one stream size classification
  - Unable to model pintro within either size class or subregion, Plains creek SDI, Ozark small river SDI
- On average, models explained ~25% of the variation in fish and invertebrate metrics in the Plains region
  - Small river pnincyp (8%) – small river nsnbenth (40%)
- Explained ~27% of the variation in the Ozark region
  - Creek pntole (13%) – small river HBI (46%)



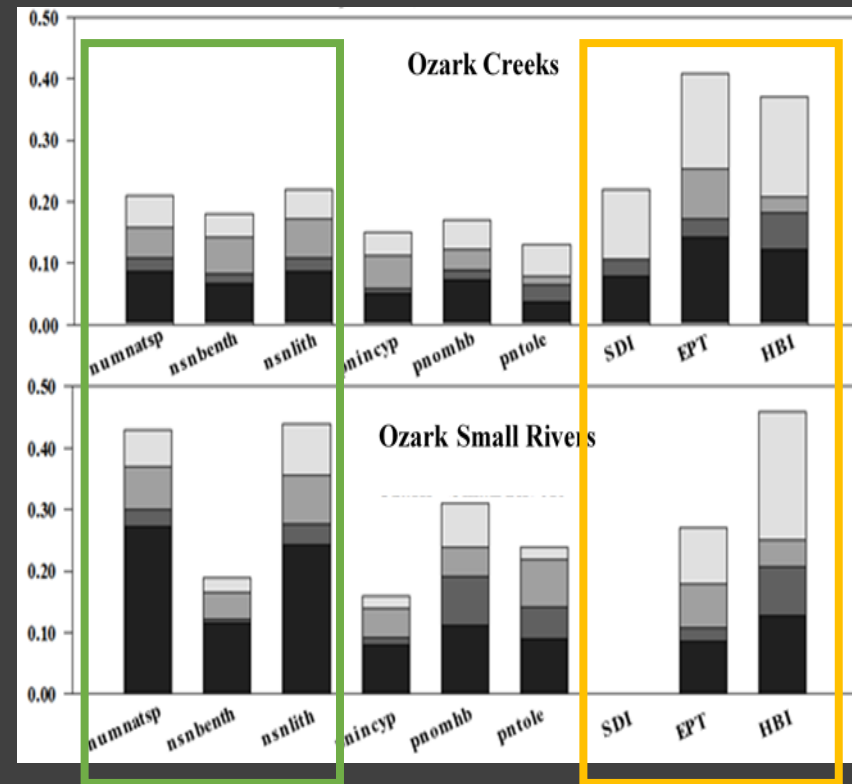
# Determining the Influence of Reach-level Environmental Variables

Proportion of Deviance Explained



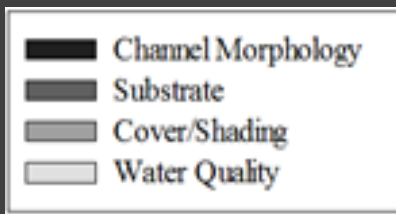
Fish Richness

Invertebrate



Fish Richness

Invertebrate



- Depth (+)
- Width/depth (+)
- SD incision height (+)

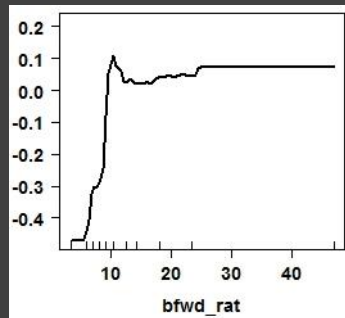


- Total Chl. (-)
- DO (+)
- Conductivity (-)

# Determining the Influence of Reach-level Environmental Variables

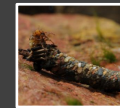
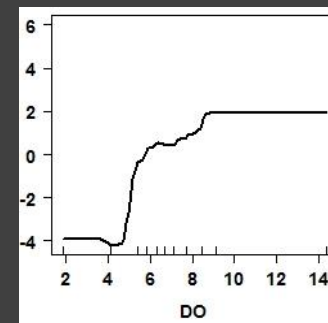
Number of Native Fish Species –  
Plains Creeks

numnat<sub>sp</sub>



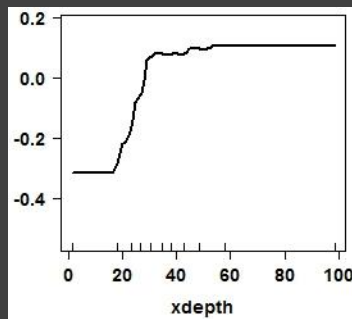
EPT Richness – Ozark Creeks

EPT Richness



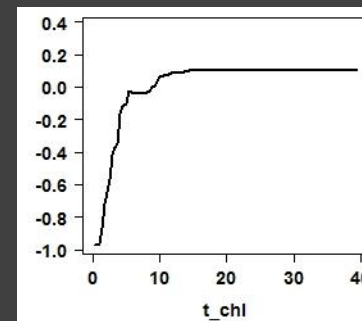
Number of Native Lithophilic  
Species – Ozark Creeks

nsnlith



Hilsenhoff Biotic Index– Ozark  
Creeks

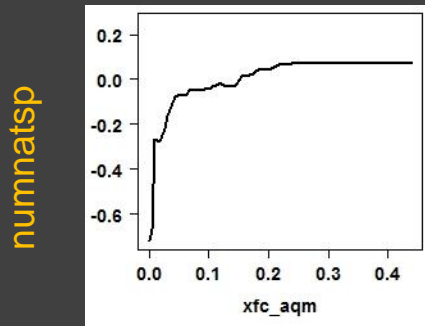
HBI



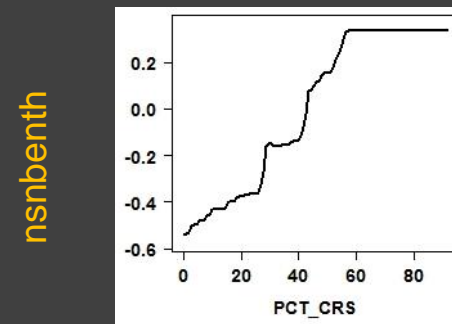


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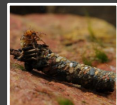
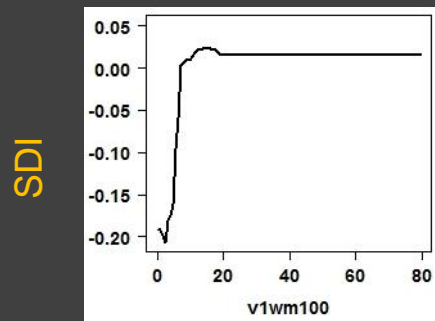
Number of Native Fish Species –  
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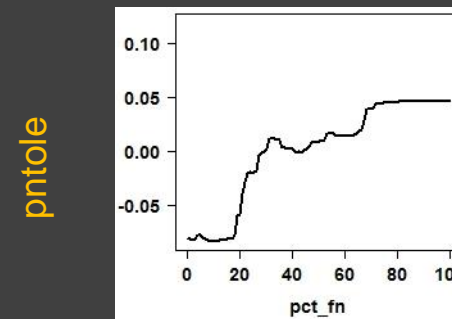
Number of Native Benthic  
Species – Plains Creeks



Shannon's Diversity Index –  
Plains Small Rivers

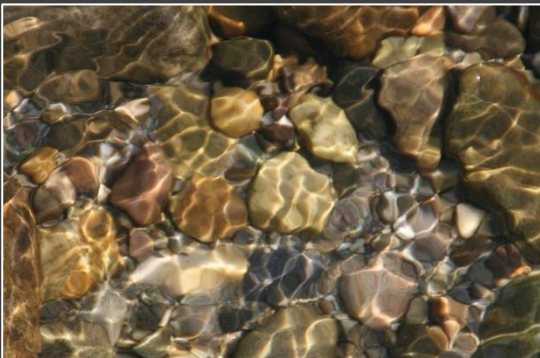


Proportion of Native Tolerant  
Individuals – Plains Creeks



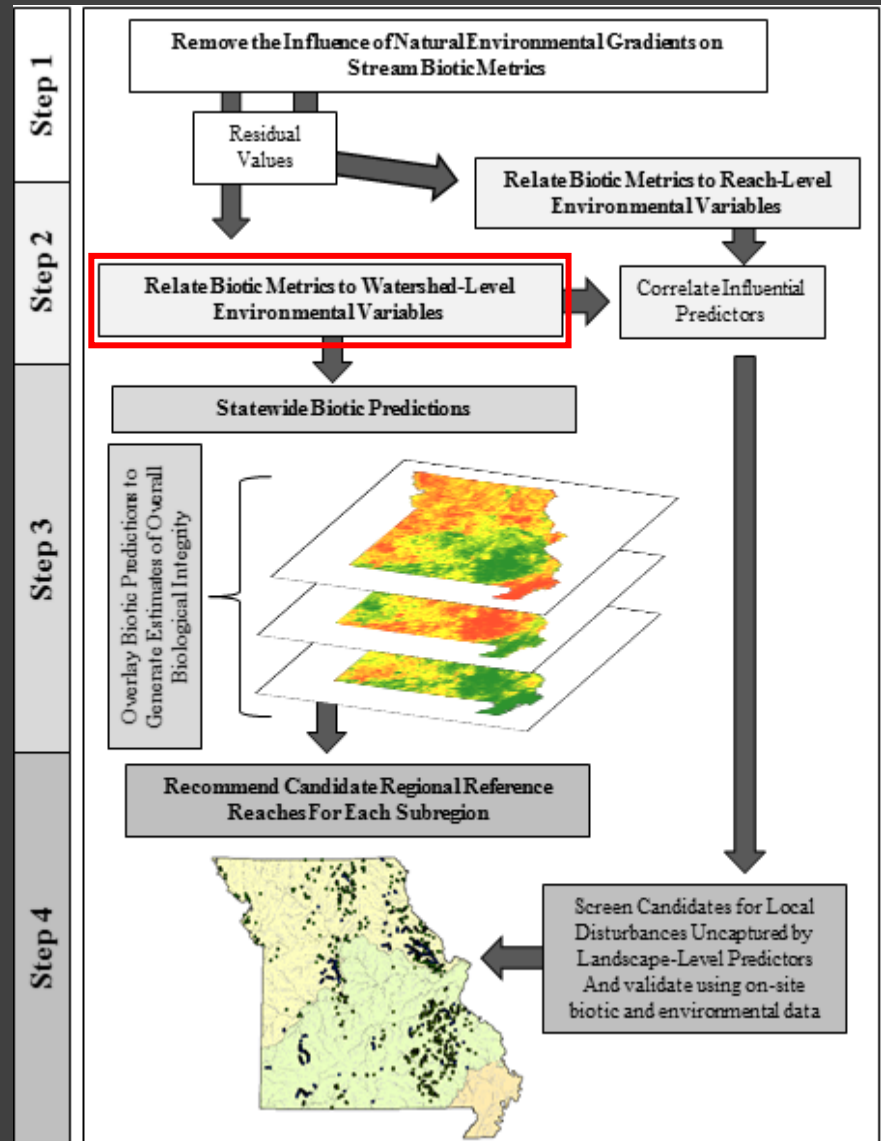
# Determining the Influence of Reach-level Environmental Variables

- **Even after removing the effect of stream size (drainage area), channel dimension is a large determinant of stream fish community structure**
  - Accounted for ~40%-50% of explained variation in number of native fish species, native benthic species, and native lithophilic species
- **Invertebrates strongly linked to water quality**
  - ~30%-40% explained variation in SDI, EPT, HBI
- **Substrate and cover/shading metrics less influential**
  - May reflect our ability to measure these parameters



# Determining the influence of human alterations and identifying least-disturbed stream reaches

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# Determining the Influence of Watershed-level Environmental Variables

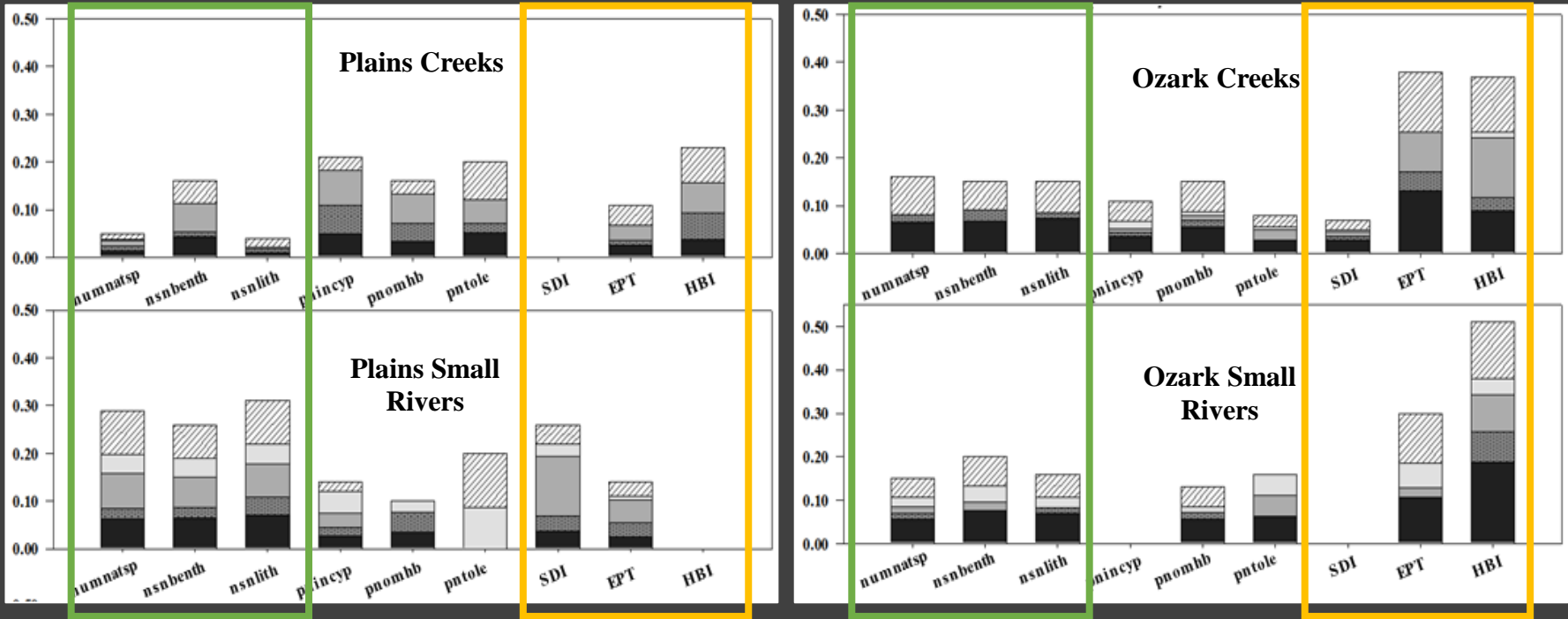
- 28 predictors evaluated after removing 34 highly correlated variables of the initial 62 (Pearson  $r = |0.70|$ )
- Successfully constructed boosted regression tree models for nine of ten biotic metrics for at least one stream size classification
  - Unable to model pintro within either size class or subregion, Plains creek SDI, Ozark small river SDI, Plains small river HBI, Ozark small river pnincyp
- On average, models explained ~18% of the variation in fish and invertebrate metrics in the Plains region
  - Creek nsnlith (4%) – small river nsnlith (31%)
- Explained ~20% of the variation in the Ozark region
  - Creek SDI (7%) – small river HBI (51%)





# Determining the Influence of Watershed-level Environmental Variables

Proportion of Deviance Explained

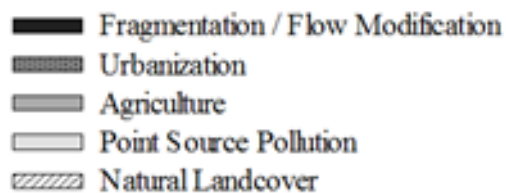


Fish Richness

Invertebrate

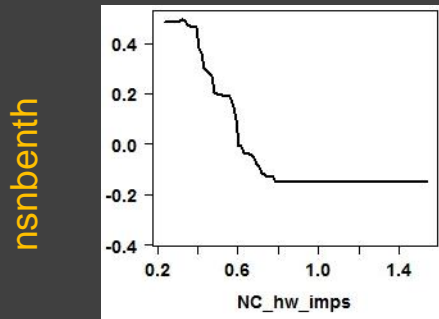
Fish Richness

Invertebrate

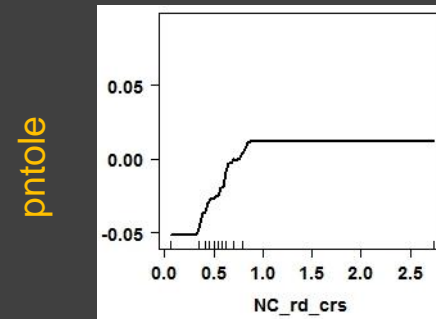


# Determining the Influence of Watershed-level Environmental Variables

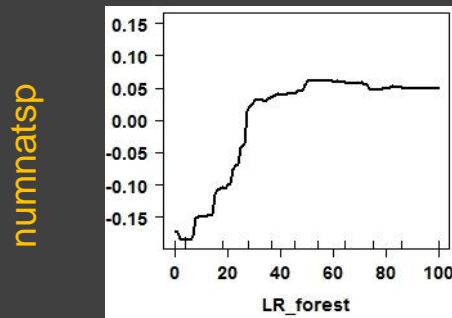
Number of Native Benthic Species – Plains Small Rivers



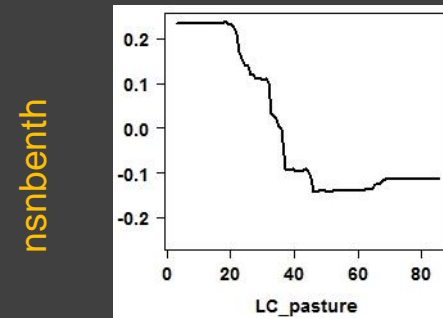
Proportion of Native Tolerant Individuals – Plains Creeks



Number of Native Fish Species – Plains Creeks



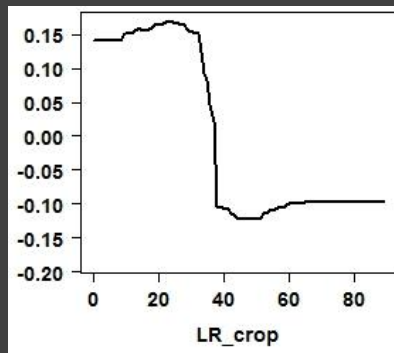
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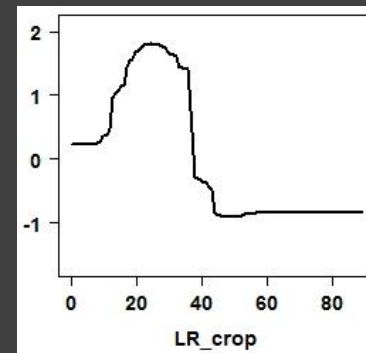
Shannon's Diversity Index – Plains Small Rivers

SDI



EPT Richness – Plains Small Rivers

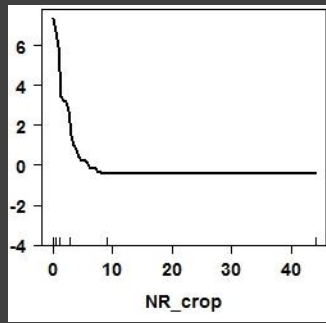
EPT Richness



# Determining the Influence of Watershed-level Environmental Variables

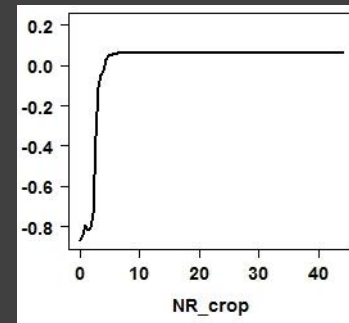
EPT Richness – Ozark Creeks

EPT Richness



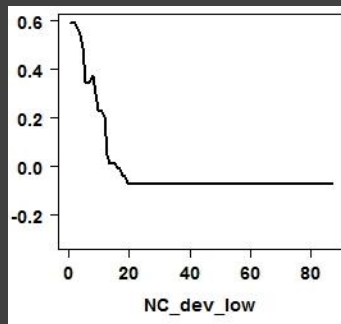
Hilsenhoff Biotic Index– Ozark Creeks

HBI



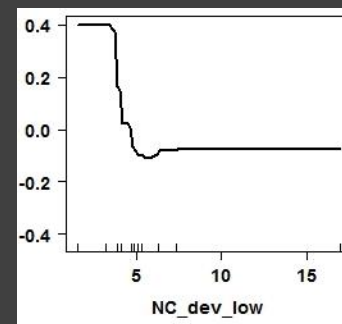
Number of Native Benthic Species – Ozark Creeks

nsnbenth



Number of Native Fish Species – Ozark Small Rivers

numnatfsp





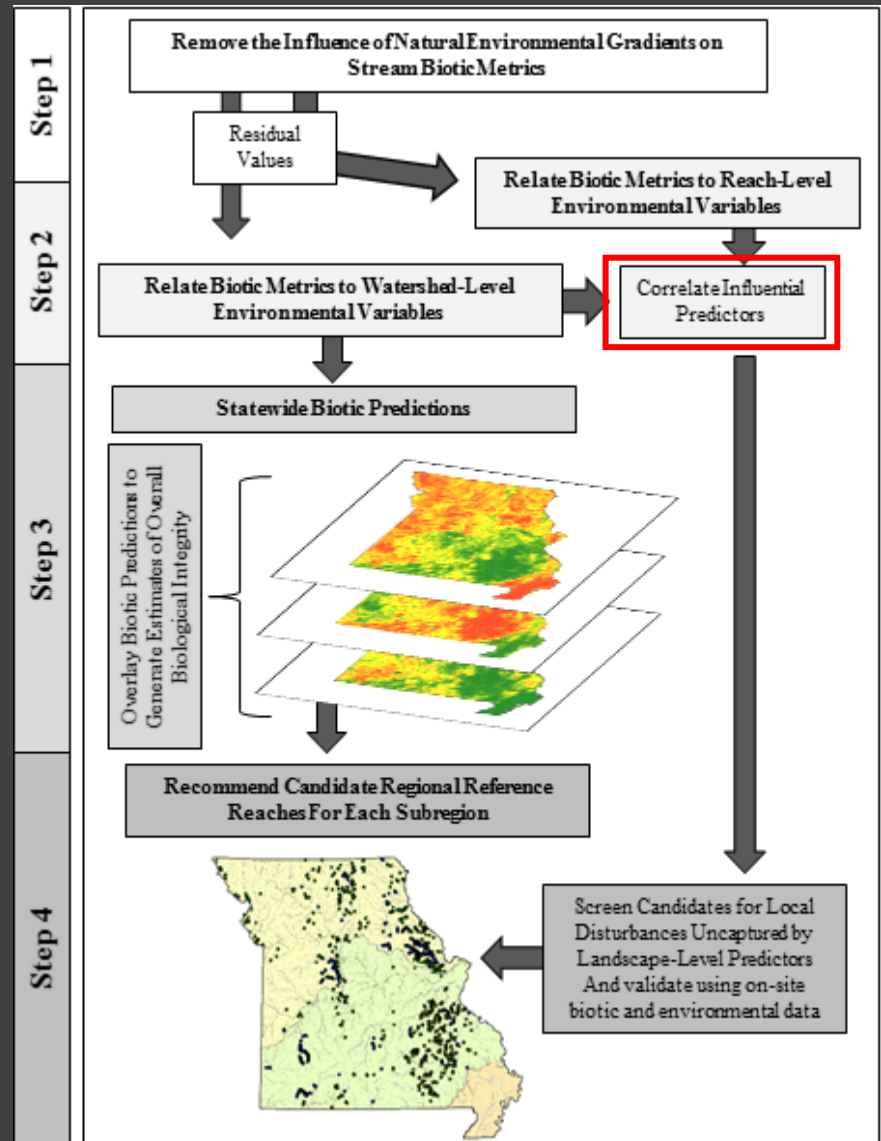
# Determining the Influence of Reach-level Environmental Variables

- **Fragmentation/flow modification in the Plains**
  - Headwater impoundment density negatively related with number of native fish species, native benthic species, and native lithophilic species
  - Communities driven by flow characteristics and water availability
  - Potential influence of piscivores
- **Agricultural disturbance**
  - Plains fish more closely related to pasture than row crop
  - Invertebrate communities in both regions sensitive to row crop
  - Plains invertebrate community impairment at ~35% riparian row crop
  - Ozark invertebrate community impairment at ~5% riparian row crop
- **Urban and point-source pollution less detectable**
  - Adequate sampling?



# Determining the influence of human alterations and identifying least-disturbed stream reaches

- **Step 1)**
  - Account for natural sources of biological variation
- **Step 2)**
  - Relate biotic metrics to
    - Reach-level environmental characteristics
    - Watershed-level environmental characteristics
  - **Link reach and watershed-level environmental characteristics**
- **Step 3)**
  - Predict biotic metrics for each stream reach statewide using watershed-level data
- **Step 4)**
  - Select streams scoring at top of biological integrity gradient as candidate reference reaches for each size class and aquatic subregion



# Linking Reach and Watershed-level environmental characteristics

- **Spearman's Rank Correlation**
  - Bold, colored numbers significant at  $P=0.05$

	xbkf_w	bfwd_rat	rpmx_dep	xinc_h	pct_crs	pct_fn	DO	t_chl	cond
NC_hwimps	<b>-0.22</b>	<b>-0.23</b>	<b>0.09</b>	<b>0.15</b>	<b>-0.16</b>	<b>0.29</b>	<b>-0.13</b>	<b>0.32</b>	<b>0.10</b>
NC_rd_crs	-0.04	<b>-0.13</b>	0.01	0.00	0.02	<b>0.08</b>	-0.01	<b>0.12</b>	0.05
LC_dev_low	-0.04	-0.05	-0.04	0.03	-0.04	<b>0.12</b>	-0.01	<b>0.21</b>	<b>0.20</b>
NC_dev_low	-0.02	-0.04	-0.03	0.02	-0.03	<b>0.12</b>	0.02	<b>0.19</b>	<b>0.20</b>
NR_crop	<b>-0.24</b>	<b>-0.28</b>	<b>-0.20</b>	<b>0.50</b>	<b>-0.53</b>	<b>0.51</b>	<b>-0.17</b>	<b>0.62</b>	0.00
LR_crop	<b>-0.20</b>	<b>-0.21</b>	<b>-0.25</b>	<b>0.45</b>	<b>-0.50</b>	<b>0.36</b>	<b>-0.10</b>	<b>0.50</b>	0.07
LC_pasture	-0.06	-0.01	<b>0.10</b>	<b>0.16</b>	-0.07	<b>0.18</b>	<b>-0.13</b>	<b>0.17</b>	-0.03
NR_pasture	-0.02	0.03	<b>0.14</b>	<b>0.10</b>	0.03	<b>0.11</b>	<b>-0.11</b>	<b>0.08</b>	<b>-0.15</b>
LC_forest	<b>0.31</b>	<b>0.34</b>	<b>0.19</b>	<b>-0.49</b>	<b>0.50</b>	<b>-0.53</b>	<b>0.18</b>	<b>-0.59</b>	0.06
NC_forest	<b>0.30</b>	<b>0.33</b>	<b>0.15</b>	<b>-0.48</b>	<b>0.47</b>	<b>-0.52</b>	<b>0.19</b>	<b>-0.58</b>	<b>0.07</b>
LR_forest	0.07	<b>0.10</b>	<b>0.24</b>	<b>-0.40</b>	<b>0.36</b>	<b>-0.31</b>	<b>0.09</b>	<b>-0.34</b>	0.03

# Linking Reach and Watershed Level Environmental Characteristics

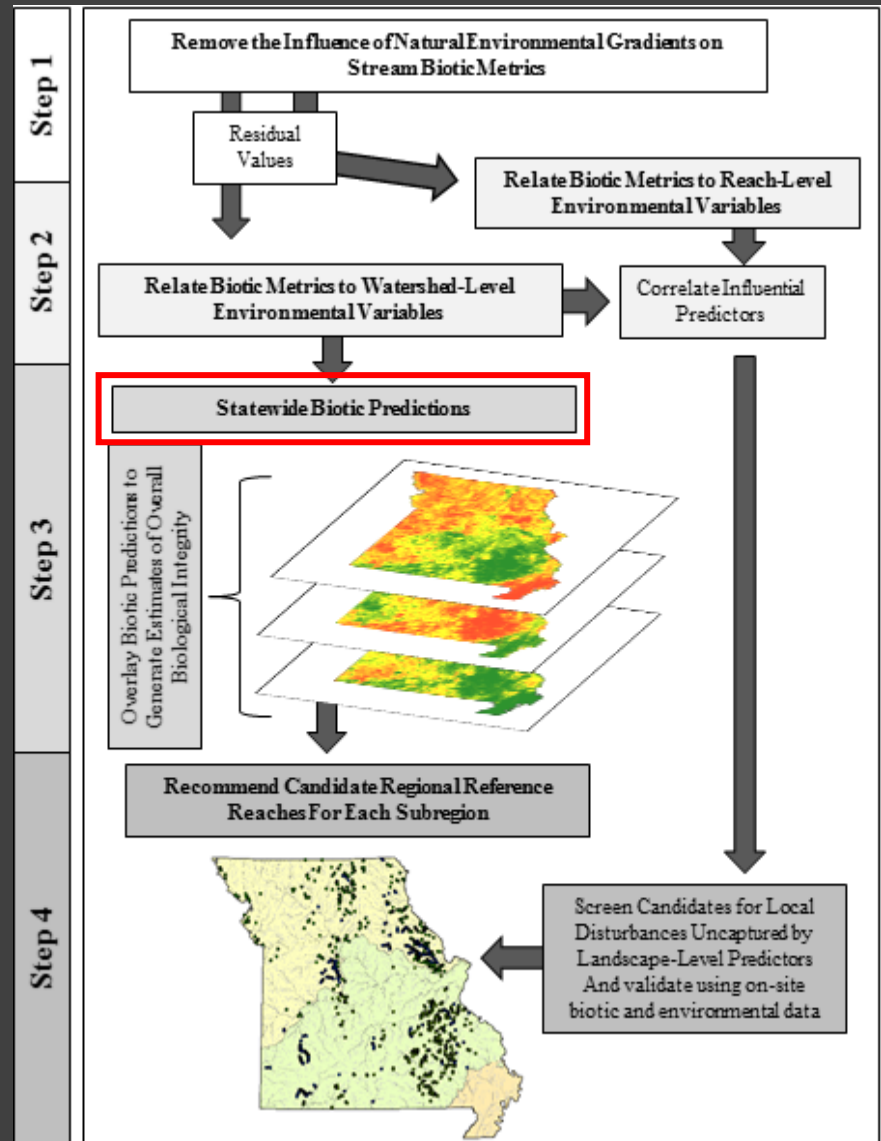
- **Spearman's Rank Correlation**
  - Bold, colored numbers significant at P=0.05

	xbkf_w	bfwd_rat	rpmx_dep	xinc_h	pct_crs	pct_fn	DO	t_chl	cond
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NC_rd_crs	-0.04	<b>-0.13</b>	0.01	0.00	0.02	<b>0.08</b>	-0.01	<b>0.12</b>	0.05
LC_dev_low	-0.04	-0.05	-0.04	0.03	-0.04	<b>0.12</b>	-0.01	<b>0.21</b>	<b>0.20</b>
NC_dev_low	-0.02	-0.04	-0.03	0.02	-0.03	<b>0.12</b>	0.02	<b>0.19</b>	<b>0.20</b>
NR_crop	<b>-0.24</b>	<b>-0.28</b>	<b>-0.20</b>	<b>0.50</b>	<b>-0.53</b>	<b>0.51</b>	<b>-0.17</b>	<b>0.62</b>	0.00
LR_crop	<b>-0.20</b>	<b>-0.21</b>	<b>-0.25</b>	<b>0.45</b>	<b>-0.50</b>	<b>0.36</b>	<b>-0.10</b>	<b>0.50</b>	0.07
LC_pasture	-0.06	-0.01	<b>0.10</b>	<b>0.16</b>	-0.07	<b>0.18</b>	<b>-0.13</b>	<b>0.17</b>	-0.03
NR_pasture	-0.02	0.03	<b>0.14</b>	<b>0.10</b>	0.03	<b>0.11</b>	<b>-0.11</b>	<b>0.08</b>	<b>-0.15</b>
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NC_forest	<b>0.30</b>	<b>0.33</b>	<b>0.15</b>	<b>-0.48</b>	<b>0.47</b>	<b>-0.52</b>	<b>0.19</b>	<b>-0.58</b>	<b>0.07</b>
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# Determining the influence of human alterations and identifying least-disturbed stream reaches

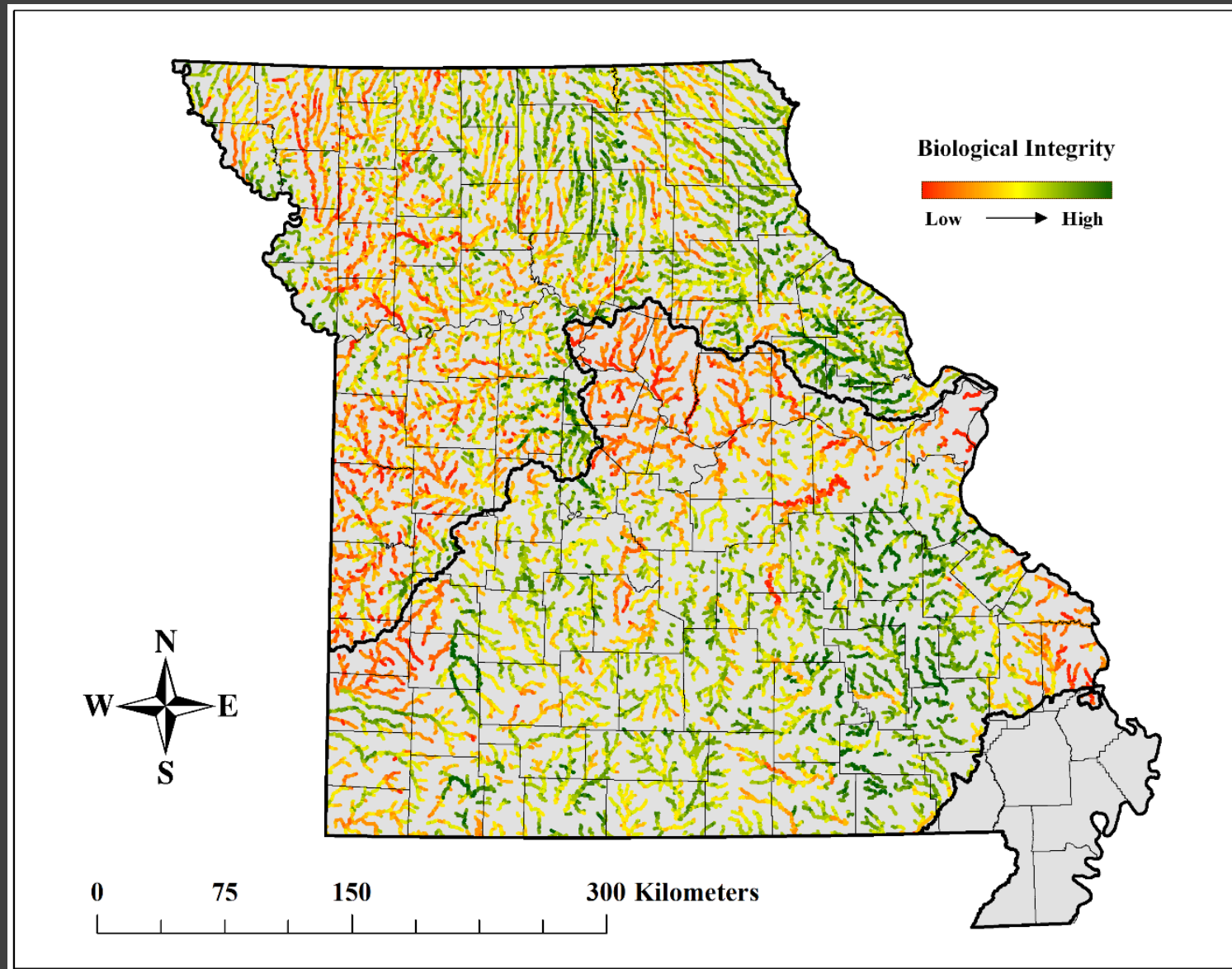
- **Step 1)**
  - Account for natural sources of biological variation
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  - Relate biotic metrics to
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    - Watershed-level environmental characteristics
  - Link reach and watershed-level environmental characteristics
- **Step 3)**
  - Predict biotic metrics for each stream reach statewide using watershed-level data
- **Step 4)**
  - Select streams scoring at top of biological integrity gradient as candidate reference reaches for each size class and aquatic subregion



# Predicting Overall Biological Integrity

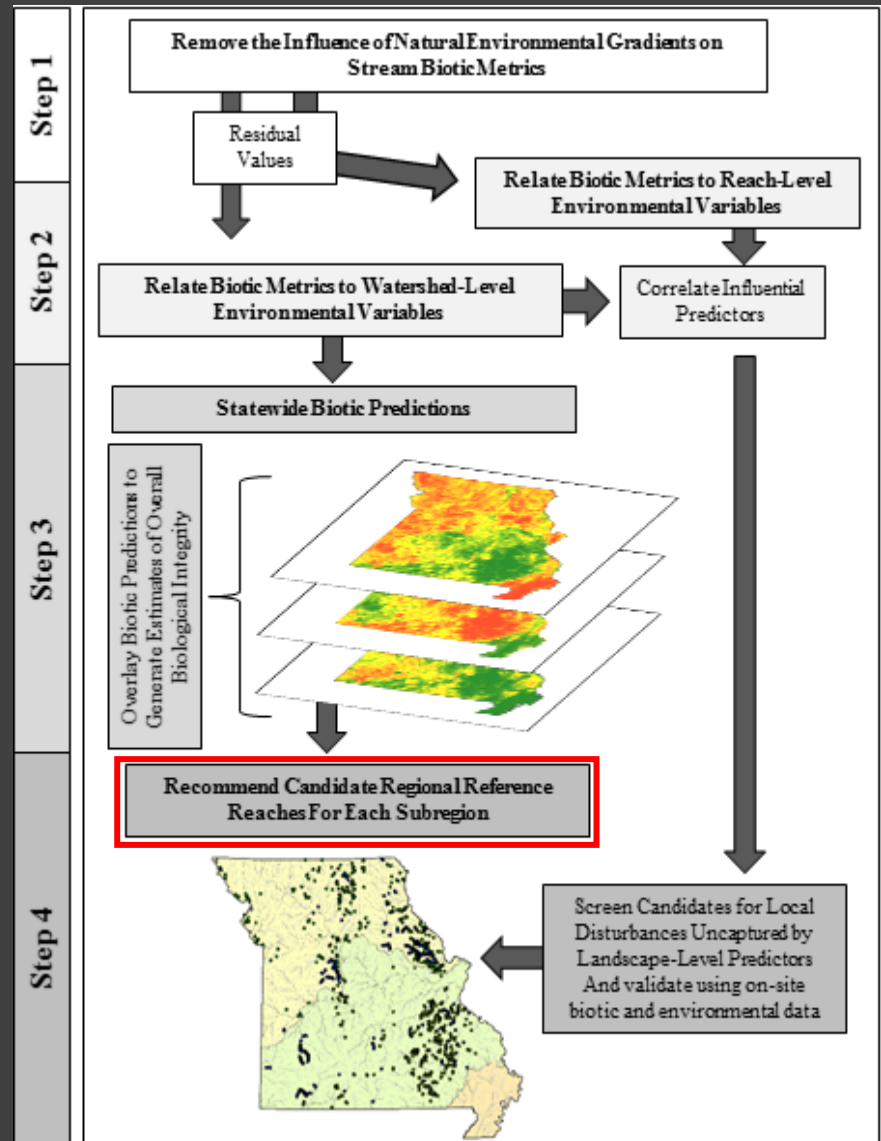
- **Used results of watershed-level models to predict biotic metrics to every creek and small river stream segment in Missouri**
  - Number of native fish species
  - Shannon's Diversity Index (invertebrate)
  - Number of native benthic species
  - Proportion of native insectivorous cyprinids
  - Proportion of native omnivorous/herbivorous
  - Number of native lithophilic species
  - Proportion of native tolerant individuals
  - Proportion of non-native individuals
  - Ephemeroptera, Trichoptera, Plecoptera Richness (invertebrate)
  - Hilsenhoff Biotic Index (invertebrate)
- **Predicted values rescaled from 0-10 and summed to generate overall estimate of biological integrity**
  - Pnomhb, pntole, HBI inverse scoring because of directionality of response

# Predicting Overall Biological Integrity



# Determining the influence of human alterations and identifying least-disturbed stream reaches

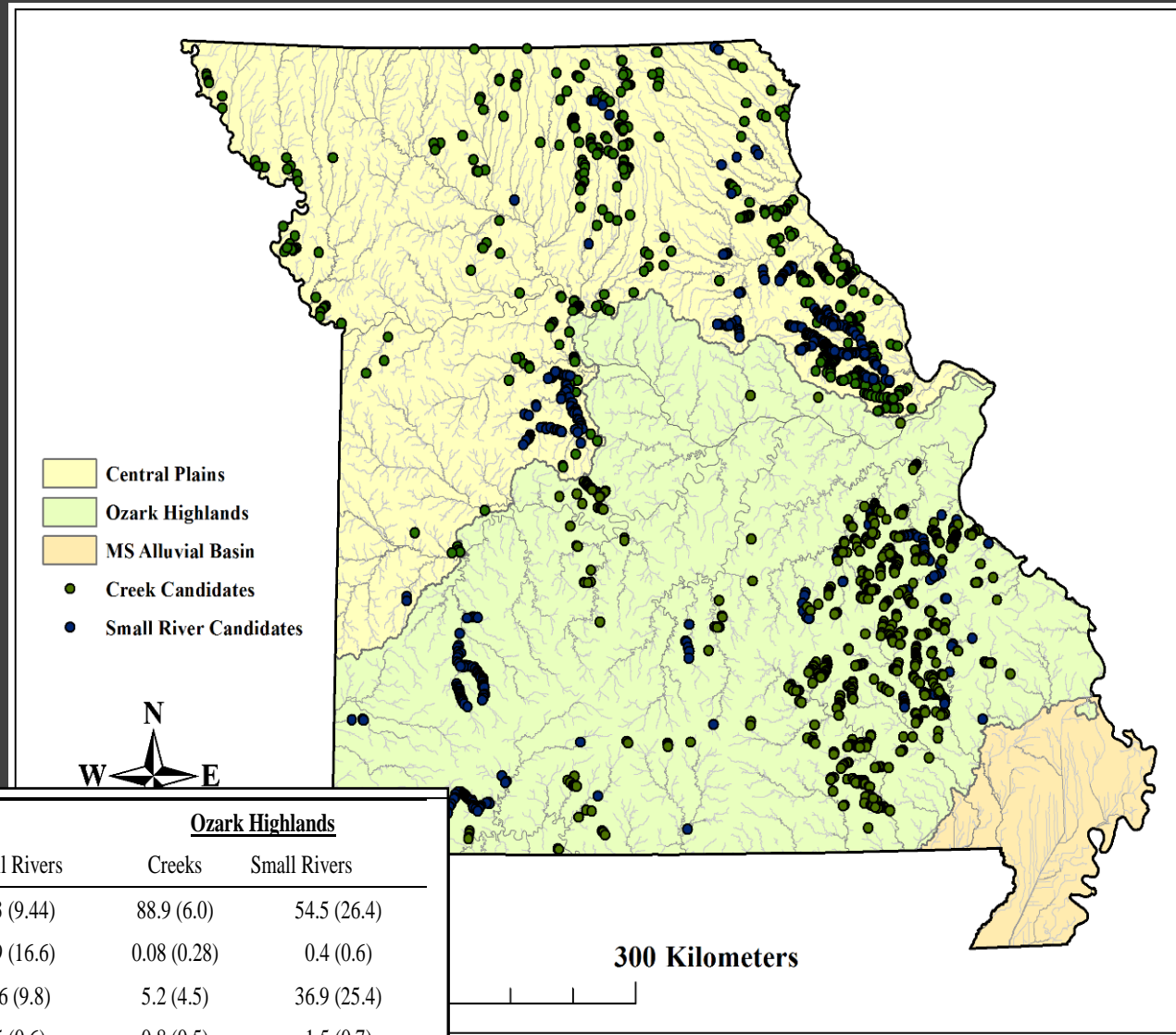
- **Step 1)**
  - Account for natural sources of biological variation
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  - Relate biotic metrics to
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    - Watershed-level environmental characteristics
  - Link reach and watershed-level environmental characteristics
- **Step 3)**
  - Predict biotic metrics for each stream reach statewide using watershed-level data
- **Step 4)**
  - **Select streams scoring at top of biological integrity gradient as candidate reference reaches for each size class and aquatic subregion**





# Identifying Candidate Reference Reaches

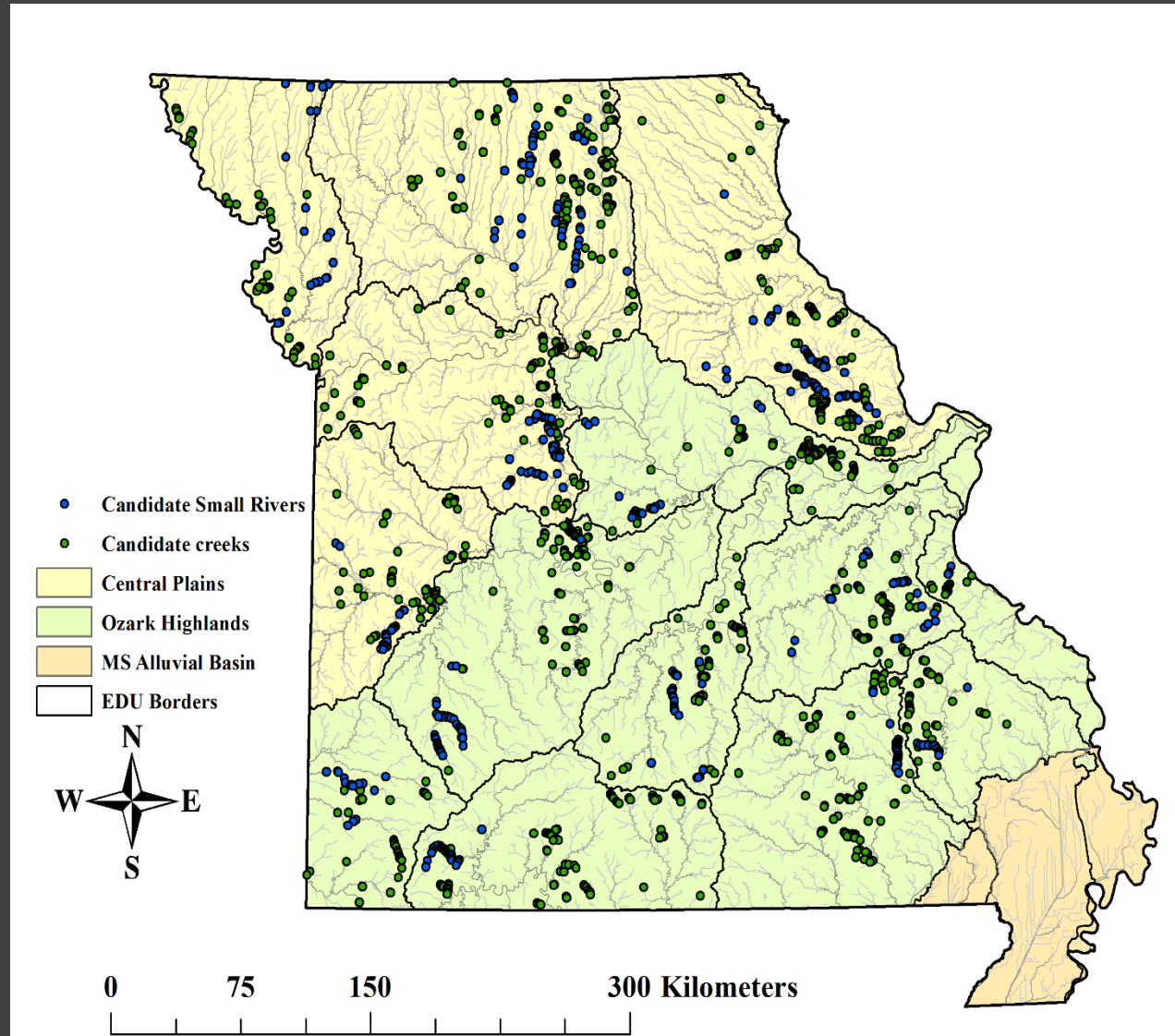
- $\geq 95^{\text{th}}$  percentile
  - Plains Creeks (448)
  - Plains Rivers (236)
  - Ozark Creeks (532)
  - Ozark Rivers (208)



Landcover/Landuse	<u>Central Plains</u>		<u>Ozark Highlands</u>	
	Creeks	Small Rivers	Creeks	Small Rivers
Forest	31.3 (15.9)	18.3 (9.44)	88.9 (6.0)	54.5 (26.4)
Cultivated Crop	27.1 (19.6)	38.9 (16.6)	0.08 (0.28)	0.4 (0.6)
Pasture	29.8 (18.6)	27.6 (9.8)	5.2 (4.5)	36.9 (25.4)
Impervious Surface	2.26 (3.1)	1.5 (0.6)	0.8 (0.5)	1.5 (0.7)
<b>Localities</b>	<b>448</b>	<b>236</b>	<b>532</b>	<b>208</b>

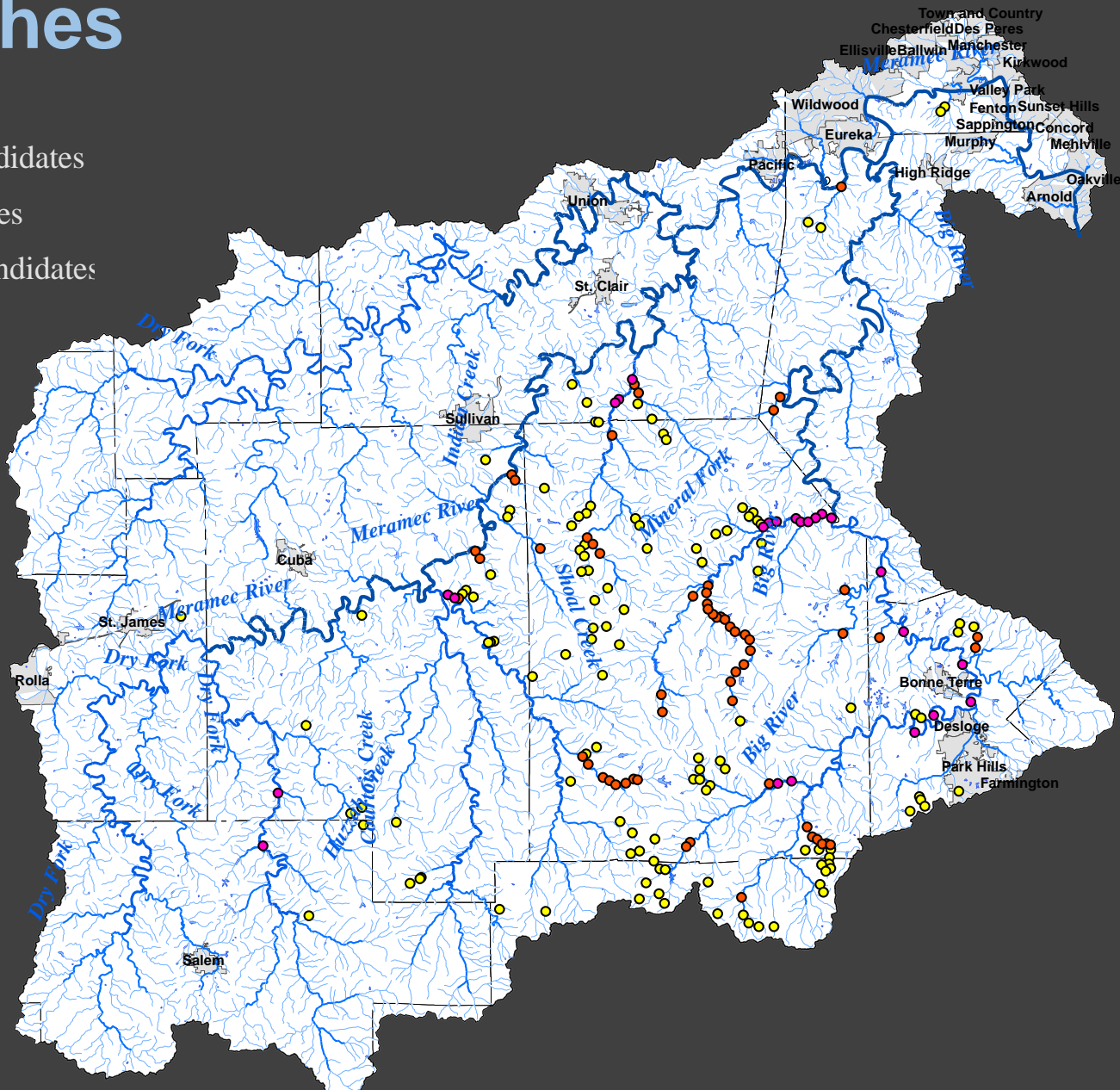
# Identifying Candidate Reference Reaches

- $\geq 95^{\text{th}}$  percentile  
by EDU



# EDU-Specific Candidate Reference Reaches

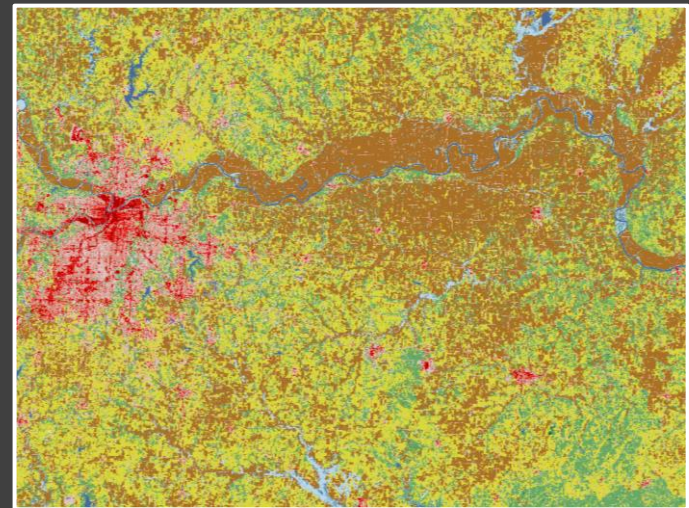
- Headwater Candidates
- Creek Candidates
- Small River Candidates





# Headwater Threat Indexing

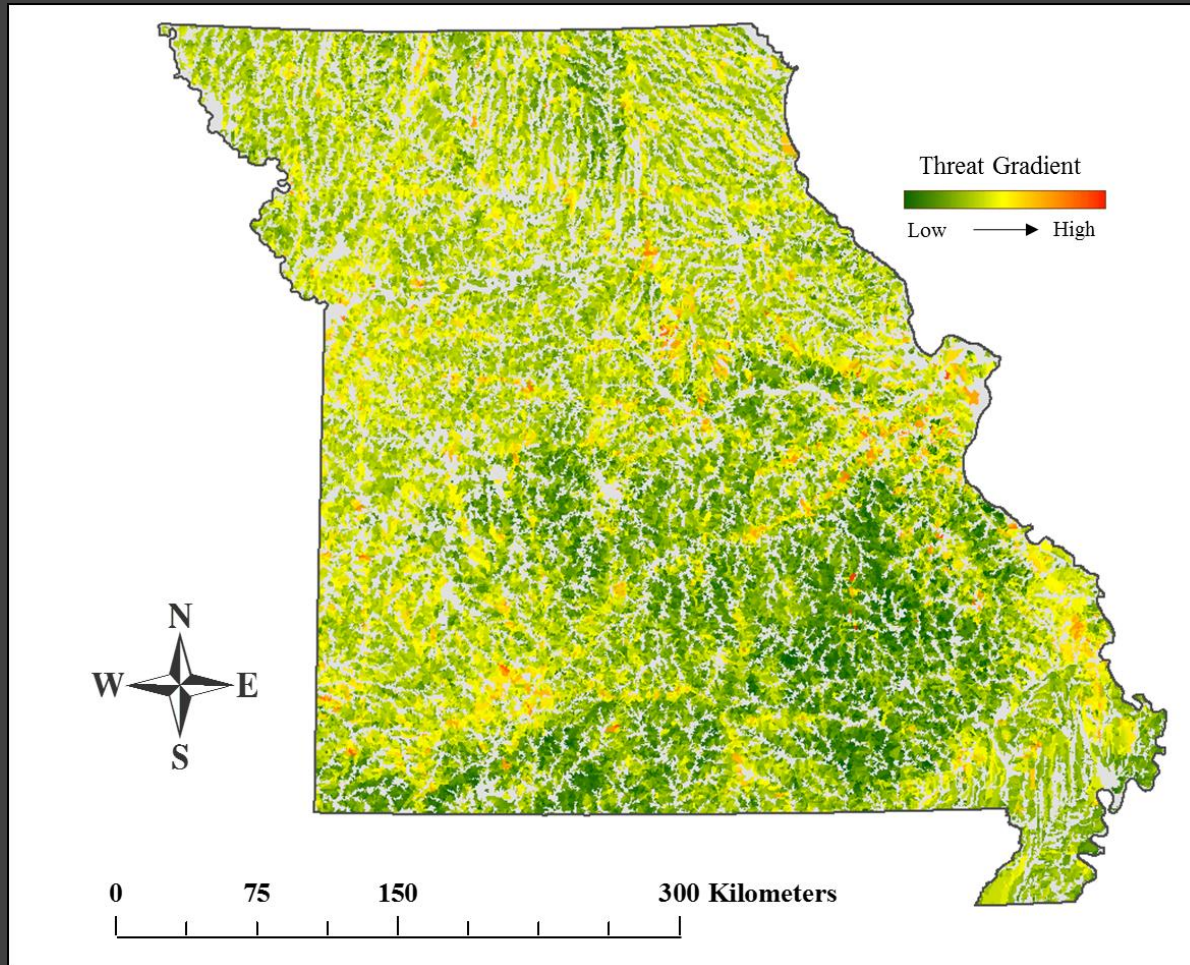
- **Headwaters are varied and diverse members of stream networks**
  - Typically  $<10 \text{ km}^2$  watershed area
  - Closely linked to landscape
  - Maintain stream flows, sediment loads, nutrient inputs, etc.
  - Often under-sampled
- **Must rely on coarse-filter conservation planning and prioritization tools**
  - Landscape-level threat indexing





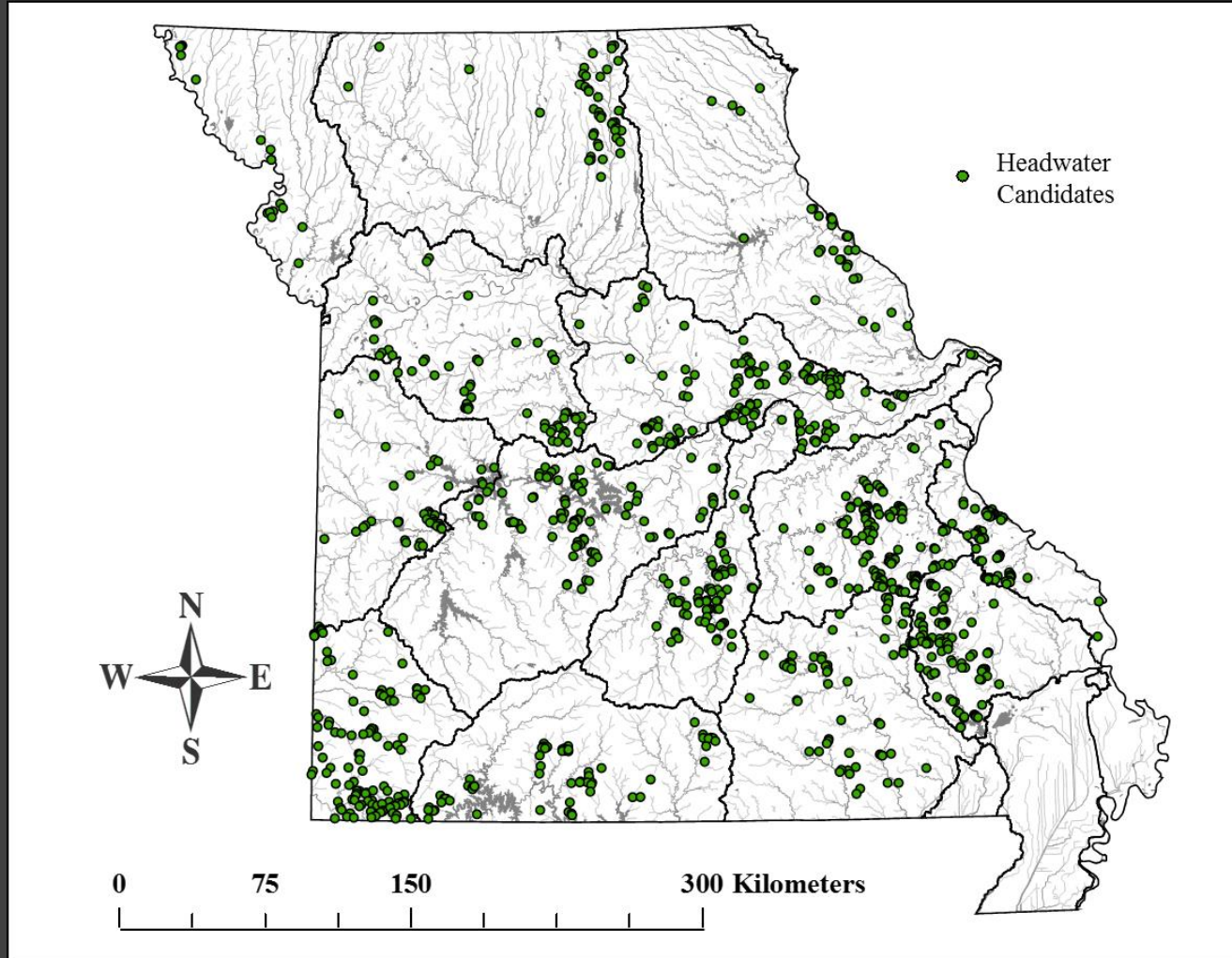
# Headwater Threat Indexing

- **Multimetric threat index results**
  - EDU-specific scores based on threat quartiles



# Headwater Threat Indexing

- Headwater candidates



# Identifying Candidate Reference Reaches

- **Best estimate of least-disturbed stream reaches within each size class and ecological drainage unit**
  - Require additional screening for local disturbances unaccounted for using landscape-level predictors (i.e. gravel mining, low-water crossings)
- **Reaches of high conservation value**
- **Benchmarks of high quality physical and biological integrity**
  - Can be used to recalibrate existing biological indices and help develop a companion physical habitat index





# Conclusions and Conservation Implications

- **Managers need the ability to:**
  - Predict areas of high and low biological integrity
  - Identify effects and sources of stream impairment
  - Conserve remaining high quality stream reaches and mitigate those already impaired
- **Our study offers a stepwise, inductive approach to characterizing the influence of anthropogenic disturbance on stream fish and macroinvertebrate communities**
- **Advantage of multi-metric approach**
- **By linking reach and watershed-level environmental conditions, we can assemble a better mechanistic understanding of the ways humans influence the physical, chemical, and biological condition of flowing waters**

# Conclusions and Conservation Implications

- **Novel framework for relating watershed-level anthropogenic disturbances to in-stream physical habitat and biotic condition**
- **Among the first to estimate biological integrity using predicted values of fish and invertebrate community characteristics**
- **Objective, data-driven approach to identifying candidate least-disturbed stream reaches**





# Conclusions and Conservation Implications

- **Improvements and future directions**
  - Incorporating additional measures of impairment (fragmentation)
  - Sample at both ends of stream scoring continuum to ensure full range of conditions are represented
  - Weighting individual biotic metrics



# Conclusions and Conservation Implications

- **Maintaining and/or restoring the integrity of flowing waters will continue to be a tremendous natural resources challenge**
  - Expanding urban and suburban areas
  - Global climate change
  - Invasive species
  - Demand for water
- **No single stream health index is sufficient**
  - Managers must use every tool available
- **Our study represents a strong first step toward refining existing bioassessment tools and ultimately conserving the integrity and diversity of Missouri's flowing waters**



# Acknowledgments

- Funding provided by the Missouri Department of Natural Resources
- Data courtesy of the Missouri Department of Conservation
- Special thanks to Matt Combes (MDC), Dave Michaelson and Randy Sarver (DNR), and Dr. Jodi Whittier, Dr. Amanda Rosenberger, and Dr. Mike Urban (University of Missouri)



Missouri  
Department of  
Natural Resources





# Questions?

